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Alley Farming in the Humid and Subhumid Tropics

Proceedings of an international workshop held at Ibadan, Nigeria, 10-14 March 1986

Proceedings

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Alley Farming in the Humid and Subhumid Tropics

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Editors: B.T. Kang and L. Reynolds

Jointly organized by the International Institute of Tropical Agriculture, Ibadan, Nigeria, and the International Livestock Centre for Africa, Addis Ababa, Ethiopia

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Abstract / Résumé / Resumen

Abstract — An urgent challenge facing scientists working on upland food-crop production in many parts of the humid and subhumid tropics is the need to find viable, sustainable, and environmentally sound alternatives to the ancient shifting cultivation and bush-fallow, slash-and-burn cultivation systems. As a food-cropping and livestock-production technology, alley farming requires a low level of inputs and helps conserve soil resources while sustaining long-term farm productivity. This publication presents the results of an international workshop on alley farming in the humid and subhumid tropics. Held in Ibadan, Nigeria, 10–14 March 1986, the workshop was attended by 100 participants from 21 countries. The theme of this workshop was the development of more productive, sustainable farming methods with low inputs in the humid and subhumid tropics using alley farming techniques. This book reviews the present state of alley farming research and its application, discusses the use of woody species in tropical farming systems, highlights training and research needs, and proposes the establishment of channels for collaborative research.

Résumé — Les scientifiques s'intéressant aux cultures vivrières en zones d'altitude dans de nombreuses régions des tropiques humides et sub-humides doivent répondre à un besoin urgent : trouver des solutions de rechange viables, soutenables et environnementalement saines aux anciennes méthodes de rotation des cultures et mise en jachère et de culture sur brûlis. A titre de technique de culture et d'élevage, l'agriculture en couloirs ne nécessite que peu d'intrants et contribue à conserver les sols, tout en favorisant la productivité agricole à long terme. Cette publication présente les résultats d'un atelier international sur l'agriculture en couloirs dans les tropiques humides et sub-humides qui s'est tenu à Ibadan, au Nigéria, du 10 au 14 mars 1986 et qui a réuni 100 participants de 21 pays. L'atelier portait sur la mise au point de méthodes culturales plus productives et plus durables ne nécessitant que peu d'intrants pour les régions des tropiques humides et sub-humides, grâce aux techniques de l'agriculture en couloirs. Le livre fait le point sur la recherche actuelle en matière d'agriculture en couloirs et ses applications, discute de l'utilisation des arbres dans les systèmes agricoles en milieu tropical, met en lumière les besoins en matière de formation et de recherche et propose l'établissement de canaux aux fins de la recherche en collaboration.

Resumen — Un reto urgente al que se enfrentan los científicos que realizan investigaciones sobre la explotación de cultivos de montaña en muchas zonas húmedas y subhúmedas de los trópicos, es la necesidad de encontrar alternativas viables, sustentables y correctas desde el punto de vista del medio ambiente, al antiguo método de cultivos migratorios y a los sistemas de cultivo en barbecho y de corte y quema. Como tecnología utilizada para cultivos alimentarios y la producción ganadera, la agricultura de pasillo o entresurcos necesita pocos medios y ayuda a conservar los recursos del suelo en tanto mantiene la productividad agrícola a largo plazo. Esta publicación presenta los resultados de un grupo de trabajo internacional sobre agricultura de pasillo o entresurco en las zonas húmedas y subhúmedas de los trópicos, celebrado en Ibadán, Nigeria, del 10 al 14 de marzo de 1986, y al que asistieron 100 participantes de 21 países. El tema de este grupo de trabajo fue el desarrollo de métodos de cultivo más productivos y sostenidos con pocos recursos en las zonas húmedas y subhúmedas de los trópicos, utilizando técnicas de agricultura de pasillo o entresurco. Este libro revisa la situación actual de la investigación sobre la agricultura de pasillo o de entresurco y su aplicación, discute el uso de especies maderables en sistemas de cultivo tropicales, subraya la necesidad de realizar investigaciones y dar cursos de capacitación y propone la creación de canales para la investigación conjunta.

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Foreword

Africa is experiencing a decline in per capita food production that presents an enormous challenge to the world's agricultural research and development institutions. Deforestation and land degradation are increasing as traditional farming systems attempt to keep pace with the demand for food from rapidly growing populations.

A cooperative effort is needed to study these trends and stem their detrimental effects. The International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, and the International Livestock Centre for Africa (ILCA) in Addis Ababa, Ethiopia, have worked together in developing alley farming. This food-cropping and livestock-production technology requires a low level of inputs and helps conserve soil resources while sustaining long-term farm productivity.

The proceedings of this international workshop on Alley Farming in the Humid and Subhumid Tropics provide a comprehensive review of the issues in alley farming. The workshop was jointly organized and hosted by IITA and ILCA, with support from the International Development Research Centre (IDRC), Ottawa, Canada, and the United States Agency for International Development (USAID), Washington, DC, USA, for which we are most grateful. The recommendations of the workshop participants will, I am sure, foster productive solutions to the agricultural crisis in Africa and deserve the careful attention of all those concerned with the future of Africa.

L.D. Stifel
Director General
International Institute of Tropical Agriculture

Introduction

B.T. Kang[1] and L. Reynolds[2]

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An urgent challenge facing agricultural scientists working on upland food-crop production in many parts of the humid and subhumid tropics is the need to find viable, sustainable, and environmentally sound alternatives to the ancient shifting cultivation and bush-fallow, slash-and-burn cultivation system. The traditionally extensive, food-crop production system, which is stable and biologically efficient, operates effectively only when sufficient land is available to allow a long fallow period to restore soil productivity, which is exhausted during the short cropping cycle. Over the years, however, the traditional system has undergone rapid changes as a result of various socioeconomic factors such as rapid population growth.

In tropical Africa, the population is increasing at an annual rate of over 3.0%. Although the land for upland farming in tropical Africa is adequate, the land available to maintain the needed long fallow period is insufficient. This has severely pressured the land productivity under traditional farming systems and has led to increased deforestation. As productive land becomes scarce, smallholders are compelled to exploit more fragile and marginal lands that cannot support large populations practicing subsistence agriculture.

The theme of this workshop was the development of more productive, sustainable farming methods with low inputs in the humid and subhumid tropics using alley farming techniques. The objectives were to review the state of the art of alley farming research and application, woody species in tropical farming systems, and training and research needs and to establish channels for collaborative research. The workshop was divided into nine sessions, with a preopening tour of IITA and ILCA on-station trials.

This volume breaks these nine sessions down into eight parts. Part 1, *Official Addresses*, presents the speeches delivered by representatives of IITA, ILCA, the Government of Nigeria, and USAID. Part 2, *Alley Cropping and Farming: an Overview*, presents three general papers on different aspects of alley farming. Part 3, *Planted Leguminous Browse*, concentrates on leguminous fodder trees. Only four leguminous trees have been subjected to in-depth scientific investigation; *Leucaena* is the most prominent of these. Foliage from leguminous trees improves the digestibility of low-protein roughage and raises the productivity both of small ruminants under cut-and-carry systems and of cattle in extensive pasture.

Part 4, *On-Farm Alley Cropping and Farming Research*, presents two papers that discuss on-farm research methods and the role of on-farm trials. Part 5, *Country Reports: Semi-arid, Humid, and Subhumid Regions*, presents 10 country papers from Africa, South Asia, and Southeast Asia. The four papers in Part 6, *Socioeconomic and Ecological Considerations*, discuss the economic returns from alley cropping to the individual and the community, the possible constraints to the adoption of alley farming imposed by land tenure systems, the role of multipurpose trees, and hedgerow intercropping. Part 7, *Networking and Collaboration*, presents two papers on research collaboration and networking with special reference to alley farming.

As the workshop concluded, participants separated into working groups to discuss research needs. The three groups discussed crop–livestock interaction, socioeconomics and on-farm research and food- and tree-crop production. Delegates then separated into two groups to consider training needs and methods of collaboration. Part 8, *Recommendations and Appendices*, presents the recommendations of all these working groups, records the establishment and plan of action of an alley farming steering committee, and lists all the workshop participants. The steering committee was selected by the African delegates in a closed session. The committee is to assist in promoting research collaboration through an alley farming network jointly coordinated by IITA and ILCA. IITA and ILCA were given a mandate to seek funding for such a network.

Part 1

Official Addresses

Welcoming address

Bede N. Okigbo

Deputy Director General, International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria

I welcome you all to this workshop on behalf of Dr L.D. Stifel, Director General of the International Institute of Tropical Agriculture (IITA). The main objective of IITA and the International Livestock Centre for Africa (ILCA) is to assist national institutions in the humid and subhumid tropics, especially in Africa, to increase food production quantitatively and qualitatively. This is done through multi-disciplinary, problem-oriented research and training in the genetic improvement of this region's major crops (maize, rice, cowpeas, soybeans, cassava, yams, plantains, sweet potato, and aroids) and in improving farming systems. This workshop deals with developments in the farming systems program, which interacts with the crop improvement program, both vital areas of concern to IITA and ILCA.

The importance of this workshop may best be realized from the fact that many developing countries, especially in Africa, suffer from food, environmental, and demographic crises. The food crisis has arisen from an inability to produce enough food to satisfy the demands of rapid population growth, urbanization, and rising incomes, especially when efforts aimed at these problems are negated by drought. Food production in Africa has not kept up with demand. It has been rising at a slow annual rate of about 1–2%; however, population has been increasing at 3.0% annually. In fact, per-capita food production has been declining for the last 15 years.

The environmental crisis is the result of deforestation, over-grazing, increased cultivation frequency, urbanization, and various other pressures of modernization. All these factors have resulted in surface soil loss through erosion and irreversible soil degradation. Ethiopia alone may lose an estimated 1 billion ($\times 10^9$) t of topsoil annually. The rapidity of deforestation, over 70% of which is due to slash-and-burn farming in Africa on at least 3.5 million ha of land each year, is beyond the regenerative capability of both the natural processes of the ecosystem and reforestation. Droughts not only have adversely affected food production but also have affected reforestation activities — water is critical and energy to work effectively under famine or even severe malnutrition falls below the critical level needed.

Consequently, there is increased reliance on food imports and foreign aid to satisfy demand. The debt burden arising from this and high petroleum bills since the 1970s has also adversely affected development programs in agriculture and forestry. The inability to import fertilizers, for example, will accelerate the rate with which new lands are brought into cultivation and, at the same time, encourage erosion and soil degradation in areas that are being cultivated. All of this calls for the development of efficient, self-sustaining regenerative farming systems that will give reasonably high yields, maintain soil fertility and productivity, and involve minimum soil and environmental deterioration, all at reduced cost, especially to the small farmer.

In Africa, over 80% of the annual increases in agricultural production is realized through expansion of cultivated area. Other strategies for increasing food production, such as high-yielding crop varieties that rely on purchased inputs, have had little impact. In fact, when tried in Africa, some of these technologies, including aspects of horizontal transfer of technologies and large-scale mechanized agriculture from temperate regions, have been very disappointing. They have, in fact, accelerated soil degradation. They have also resulted in agriculture being practiced at the expense of forestry.

There are some ecologically sound and productive farming systems that have been successful. These include plantation agriculture for cocoa, coffee, rubber, and oil palm; the Asian wet rice production system; and the coconut pasture and related agroforestry and agrisilvopastoral systems. Even so, these systems have often been bedeviled by numerous socioeconomic and political problems on the African continent.

Our most serious challenge stems from the fact that we are attempting to develop improved farming systems for growing food crops through the introduction of annual field crops into an ecological zone where the climax vegetation — the tropical rain forest — is adapted to rainstorms, high night temperatures and other environmental stresses of tropical climates. It is for this reason that finding ecologically sound, economically viable, and culturally acceptable alternatives to shifting cultivation and related fallow systems has remained intractable, especially in the humid and subhumid tropics. Herein lies the task of IITA's farming systems program, of other international agricultural research centres such as ILCA, and of national institutions that are facing the same problem.

In our farming systems research, we have given priority to understanding the farmers' overall environment, production systems, and constraints to increasing production. IITA is emphasizing developing technologies for improved cropping systems in an environment fraught with numerous socioeconomic problems, not the least is that of deficiencies in infrastructure and policies. We have learned that the traditional farmer lacks credit and wants to produce reasonable levels of a range of commodities for food and cash at reduced risk and cost.

For this reason, IITA's farming systems research has tried to find meaningful and scientific ways of modifying traditional technologies and practices. We are attempting to integrate selected components of traditional farming systems and compatible but ecologically and economically sound components of modern farming systems. In doing so, we hope to develop new subsystems of production and strategies for soil and other resource-management systems that can be used by resource-poor farmers. We have also taken advantage of our ecological knowledge to design some agroecosystems that mimic the natural multistoried structure of tropical forest ecosystems.

Alley cropping is the result of long-term efforts in integrating traditional and modern or emerging technologies. It involves growing food crops between rows of selected fallow species (such as *Leucaena*). These fallow species are preferably fast growing, capable of fixing atmospheric nitrogen efficiently, or incapable of fixing nitrogen (e.g., *Acioa* and *Alchornea*) but efficient in cycling nutrients and dropping litter year round.

The traditional farmer already uses natural or planted fallows, but these are not grown in rows. The farmer prunes fallow trees and shrubs and makes good use of their litter; sometimes, however, trees and shrubs are burned. The farmer grows crops between stumps of varying heights, uses cut branches for fuelwood, and uses stumps left in the field for staking. However, the traditional farmer ties down a lot of land in fallow. Under population pressure, fallows are ineffective in maintaining soil fertility. The longer the fallow, the more labour is required for land clearing. Moreover, traditional farmers do not always conserve soil by planting along the contour; this can be done in alley farming. The traditional farmer uses fallow species as animal feed; however, this is often not as efficiently managed as in alley farming. Based on these considerations, alley farming has developed into a system that achieves the following objectives:

- maintenance of soil fertility through nitrogen fixation and nutrient cycling;
- maintenance of adequate levels of soil organic matter;
- supply of mulch for protecting the soil and regulating water infiltration, runoff, and erosion;
- supply of fuelwood;
- supply of stakes and ligneous materials that can be put to industrial use;
- supply of browse or fodder for animal feed; and
- limiting fallows to narrow strips, consequently saving land and making possible continuous farming with or without very short fallow periods.

Alley farming can more than double the land area under cultivation without resorting to a change in land tenure. Within alley farming, many cropping patterns are possible. For example, alley farming allows some aspects of multistoried cropping that mimic nature (plantain–cocoyam cropping or integration with animal production).

IITA cannot achieve all of these objectives alone. Its mandate does not include animals as does that of other international agricultural research centres, such as the International Centre for Tropical Agriculture (CIAT), ILCA, and the International Laboratory for Research on Animal Diseases (ILRAD). It is for this reason that IITA has jointly conducted its research and training in this area with ILCA. On behalf of the Director General and my colleagues at IITA, I wish to express IITA's appreciation for the cooperation we have enjoyed from ILCA.

The objectives of IITA and ILCA in organizing this workshop are

- to review the state of the art in alley cropping or farming systems research and applications;
- to review the role of cultivated trees and shrubs in farming systems;
- to establish channels for collaboration;
- to identify gaps in our present knowledge and research; and

- to share ideas and research methods that will facilitate the realization of the full potential of alley cropping.

I plead that we do not get involved in arguments as to whether alley farming is agroforestry or an agrisilvopastoral production system. The main objective of alley farming is to maintain soil fertility, maintain the productivity of crops and compatible animal species, and to minimize erosion. Of course, many fallow species used in alley cropping are multipurpose and ligneous species that can be used in agroforestry. We can gain a lot by discussing what can be achieved and what has to be done to achieve it. We can accomplish little if we spend hours on definitions. We still face the problem of how to extend alley farming to various ecological zones and how to develop various cropping combinations and sequences within alley farming.

During your stay, I hope that you will acquaint yourselves with all aspects of IITA's activities and make good use of our facilities. I wish you successful deliberations and a fruitful exchange of ideas.

Opening address

Kurt J. Peters

Director of Research, International Livestock Centre for Africa,
Addis Ababa, Ethiopia

On behalf of the International Livestock Centre for Africa, I welcome you all to this workshop on alley farming in the humid and subhumid tropics. ILCA, as a coorganizer, takes great interest in alley farming. We hope that this workshop will be a fruitful experience for all participants.

ILCA's main objective is to improve food production in sub-Saharan Africa by fully utilizing the catalytic and integrated functions of livestock production in African farming systems. Whether integrated into the cropping sector through draft power and manure production or as a sideline to improve financial liquidity, livestock production in sub-Saharan Africa is basically limited by two major constraints: disease and nutrition. With the exception of viral diseases, many diseases are related to malnutrition. Thus, any attempt to improve livestock production needs first to overcome nutritional problems.

Crop residues and coarse pastures are the major feed resources for African livestock. ILCA's strategy is to maximize the use of these feeds by providing a better environment for rumen microbial organisms. This is being done through strategic supplementation with fermentable nitrogen and other critical growth factors, which, in the humid zone, may also be fermentable energy and minerals. Farm-grown legumes are the best source for improving nutrition and crop production. ILCA is working with many types of herbaceous and woody grain and browse legumes, seeking those species adapted to particular ecological conditions and farming systems.

Increasingly, attention is turning to legume browse species and their use in agroforestry systems. *Leucaena* offers specific scope, after microbial degradation of 3-hydroxy-4 (IH) pyridone (DHP) alleviates mimosine toxicity and allows feeding at a much higher rate.

After dealing with a variety of farming systems, ILCA has focused its interest on the production of forage legumes through alley farming, intensive feed gardens or fodder banks, compound hedges, and relay and intercropping. With the advantage of collaborating with IITA, ILCA's Humid Zone Programme has turned to the forage-production component of alley farming and legume feed gardens. After initial on-station tests of these systems for fodder production, the team, some 5 years ago, initiated on-farm tests to evaluate these systems, their social acceptability, economic benefits, and technical feasibility through a multidisciplinary approach. Farming system research methodology includes the following five steps:

- understanding the farming system (diagnosis);
- identification of constraints to livestock production;
- searching for solutions;
- on-station and on-farm testing of solutions; and
- improving solutions through feedback from on-farm tests and modification of technology.

After 50 work years of study by professional staff at IITA and ILCA, certain solutions should now be ready for the extension service system and these could be taken out to other sites in the humid and subhumid zone. The immediate partners in such an outreach activity are scientists, trainers, developers, and planners at national institutions interested in utilizing and implementing or adapting the new, appropriate technology to circumstances in their countries. Therefore, strengthening national agricultural institutions is an essential component of ILCA's strategy to improve food production for the benefit of its ultimate clients, the small farmer.

This workshop will give researchers a first-hand opportunity to exchange views on options of farming-system improvement, to review potential tree legumes from various countries, to identify gaps in knowledge, and to determine the need and basis for future collaboration. I hope that this workshop will be a starting point for a sustained, productive future collaboration between national institutions, donors, and the international research centres — IITA and ILCA — for improving food production in Africa.

Inaugural address

D.E. Iyamabo

Coordinating Director of Science and Technology, Federal Ministry of Science and Technology, Lagos, Nigeria

Nigerian and, indeed, African agriculture have far more problems than crop productivity. Government policies and the capacity of natural production factors sometimes appear taken for granted. Appropriate government policies are necessary for successful agriculture. So, also, are good soils, adequate water, and abundant vegetation; factors that form the bedrock of our agricultural production. In the humid and subhumid tropics, water is not regarded, sometimes erroneously, as a major problem. In semi-arid and arid areas, water management is critical. In all the tropics — humid, subhumid, arid, and semi-arid — soil and vegetation are major elements in productivity; elements that deserve far more attention than they now receive.

A traditional farmer experiences changes in soil fertility; these changes can lower crop yields if the same piece of land is farmed continuously. The farmer may not understand yields have declined and may deal with the problem by moving to another piece of land. The scientific farmer, however, uses fertilizers to keep the crop yield high. This will extend the productivity of the land a few more years, but the decline in yield eventually occurs, soil structure deteriorates, and erosion begins. This is the dilemma of tropical agriculture — in the meantime, shifting cultivation flourishes.

Solutions to these problems can be found in research and evaluation of soil-management practices and farming systems — systems that ensure soil fertility and soil stability, necessary for sustained high productivity, at fairly low costs.

Considerable research is devoted to genetically improving crop yields, disease resistance, and drought tolerance. By contrast, little research is being done on the problems just mentioned, particularly soil management. Research in these areas is not particularly attractive. The experiments are virtually all in the field, their gestation periods are long, and results are neither spectacular nor glamorous; therefore, any advancements do not easily win the appreciation of farmers, the public, or policymakers. As a result, scientists and institutions may tend to avoid this kind of research, on which agricultural productivity ultimately depends. The importance of such research has, however, long been stressed by agronomists and soil experts worldwide. The most recent call was by the study group on the impact of the Consultative Group of International Agricultural Research (CGIAR) centres on agricultural production in the Third World.

Alley farming research is in line with these needs. It involves growing perennial trees in systematic rows, and the production of arable crops between these rows; in essence, growing trees and food crops on the same piece of land. Depending on the tree species, such practices may help to improve soil fertility, hold soil particles together and prevent erosion, and produce shade, browse for livestock, poles, fuelwood, and other forest products.

The benefits of growing perennial trees with arable food crops have been recognized for a long time and "alley cropping" has been practiced in various forms over the ages. These practices have evolved for different reasons. For example, some traditional farmers leave trees on their farms because they are too big, sacred, or are useful as shade or fruit trees. A few, such as *Acacia nilotica*, are usually not cut because of their ability to improve soil fertility. Cocoa farmers leave shade trees such as *Terminalia ivorensis* and bananas for the benefit of their cocoa seedlings. Foresters encourage the combined growth of trees and food crops to satisfy the hunger for agricultural land, to obtain interim revenue from their plantations, and to promote the complete utilization of soil, sunlight, and other production factors. This practice has led to the discipline now universally recognized as agroforestry.

However, none of these practices was based on data from systematic and scientific research. Results from such research form the basis for evolving fairly exact production systems and technologies that can be applied in different situations. So far, the work on alley farming has done just this.

Scientists at IITA and their colleagues at the International Centre for Tropical Agriculture (CIAT) pioneered the rethinking of agricultural production in the tropics, which ultimately focused world attention on farming systems. The emphasis was on the production system rather than on crop improvement. From their work, IITA evolved the technologies of minimum tillage and no tillage, which were significant advances in crop production. From experiments on the west bank of the IITA campus and the land-use research project sponsored by the United Nations University in Okomu Forest Reserve in Bendel State, IITA is accumulating scientific data that hopefully will sprout soil-management technologies capable of sustaining high production and, at the same time, maintaining good soil structure.

Alley farming involves soil and vegetation management and has engaged the attention of IITA and ILCA scientists for some years now. The results of initial alley farming trials seem very promising. In any case, these scientists now feel that their work can be reviewed, possible applications explored, and future, collaborative research mapped out. Although not anticipating the outcome of the workshop, it seems to me that we are on the threshold of a major development in tropical agriculture. Alley farming appears to have the potential to

- reduce farming costs by improving soil fertility, thus minimizing mineral fertilizer requirements;
- stabilize soil and reduce erosion;
- provide browse for livestock and fuelwood for energy;
- be applied in all soil and farming situations; and
- be easily demonstrated.

I have no doubt that a farming system that has these attributes will make a tremendous impact on agricultural production in this country and elsewhere. I congratulate IITA on this achievement. I also congratulate ILCA for its collaboration. I would also like to commend the International Council for Research in Agroforestry (ICRAF) and the national institutions that have joined in this workshop; and I am grateful to the International Development Research Centre (IDRC) and the United States Agency for International Development (USAID) for sponsoring this international workshop. I wish it the success it richly deserves.

We in Nigeria are very interested in this research on alley farming and will do all we can to support it. We fund a nationally coordinated research project on farming systems research, which involves our food crops research institutes and our universities. In addition, our institutes carry out farming systems research within their mandates. The Forestry Research Institute of Nigeria, together with the University of Ibadan, is active in agroforestry research. To strengthen this research, the Federal Ministry of Science and Technology is now negotiating what may prove to be a very useful, collaborative agroforestry research project on the utilization of vertisols, between the University of Wales in the United Kingdom, the Lake Chad Research Institute in Maiduguri, Nigeria, and the Forestry Research Institute of Nigeria in Ibadan. These national research institutes and the National Animal Production Research Institute of Nigeria will be encouraged to intensify collaboration with IITA.

The promise of alley farming should not make us rest. Further research needs to be done on other soil types, different tree species, different food crops, and different ecological conditions. Collaboration between agricultural and forestry scientists needs to be intensified. Many agriculturists unfortunately have not accepted the concept of agroforestry as beneficial to arable crops; the cause of alley farming requires a champion. Training courses in agroforestry and alley farming for students and farmers should be introduced in universities, schools of agriculture, schools of forestry, and research institutions. Public-enlightenment programs are necessary in areas prone to erosion, desertification, and similar ecological disasters.

Developments such as we are seeing in alley farming and in other areas of agricultural research give cause for optimism that the technical problems of agriculture in Nigeria and, indeed, in all of Africa can be solved. We need to identify the problems correctly, mobilize ourselves to tackle the problems, and incorporate the useful results from the research into production processes.

Final address

T.M. Catterson

Senior Forestry Adviser, United States Agency for International Development, Africa Bureau, Washington, DC, USA

I am sure you are all well aware of the dramatic circumstances of drought and famine that have afflicted major parts of this continent and that culminated in a massive campaign of famine relief in 1984/85. This situation once again brought home the fragility of existence that confronts the millions of people in Africa. Fortunately, the 1985 rainy season was generally good and food production has increased. It is not a time, however, to be complacent, whether you find yourself in the semi-arid north or in the forest zone. We are all aware that, for Africa, food production per capita has declined against the backdrop of expanding populations. Feeding the people is still the major development challenge of the 1980s and it is likely to continue to be so during the 1990s.

Why then are we concerned with trees? The USAID food strategy for Africa concentrates mainly on the following elements:

- policy review and changes to encourage increased food production;
- PL 480 Food for Peace program to help fill the gap until domestic production can meet demand; and
- agricultural research and the transfer of technology for improvement of crops and their production techniques to enhance yields.

Policy reforms to provide the appropriate policy–institutional environment to stimulate and favour individual farmers and private-sector investment and production can be very effective. There has been and will continue to be strong support among the American people for humanitarian assistance, as and when required.

Since late 1985, with the famine behind us, the media, the American public, and their representatives are urging us to do more — to work on the basic issues that undermine agricultural productivity in Africa. Environmental degradation and desertification are important elements in the production equation.

Continued strong support for agricultural research in Africa will be necessary. Indeed, after considerable review, USAID recently issued its *Plan for Strengthening Agricultural Research* in the region. The objective of this document is to improve the effectiveness and efficiency of our widespread efforts in this field. The Agency recognizes, however, that improved and hybrid varieties of food crops and appropriate farming systems — the green revolution that must surely come for Africa — will all require good, fertile, well-watered, stable soils in which to prosper.

Agricultural research results will be of little use if the soil in which the crops must grow is

- too impoverished to nourish the improved seed,
- too degraded to hold what rain does fall, and
- too bare to avoid being blown away by wind or eroded by sudden and intense rains.

In short, we feel that, in addition to striving to modernize agriculture, it is critical to be mindful, over the short and medium term, of the need to cope with droughts, desertification, soil degradation, and environmental decline. We must reemphasize efforts to conserve the ecological base on which land-use productivity so critically depends. We need to look carefully at the constraints many farmers still experience in obtaining fertilizer and at the foreign-exchange demands this fundamental input can place on the already stressed balance-of-payments situation.

Forestry endeavours can certainly play a part in meeting some of this challenge. The tremendous expansion of forestry programs throughout Africa since the early 1970s was indeed a recognition of environmental problems. It is interesting to note, however, that in reviewing our forestry programs in Africa, and I think other donor agencies share this experience, we found them to be too narrowly focused on the so-called fuelwood problem. Where fuelwood is getting scarce, one finds on closer examination that inevitably many other components of rural production systems are under stress. Fuelwood simply is not as important to the farmer, large or small, man or woman, as food, the health of the children, shelter, a livelihood, or, indeed, survival itself.

Food comes first. Frankly speaking, if you have no food to cook, you do not really have a fuelwood problem. I believe that in the past we have taken too sectoral an approach to land-use problems, tending to leave the forestry issue in the hands of foresters, thereby further exacerbating the dichotomy between agriculture and forestry.

What we really need is a pragmatic integration of agriculture and forestry, building on traditional systems and on the inputs already available to the farmer: the land, labour, capital, and technology that is used on a day-to-day basis. It will be the farmers planting trees on their lands because they are interested in the immediate economic benefits — either from direct impact on agricultural productivity or from tree products such as food, fodder, fuelwood, and poles — who will begin to make the substantial impact required to restore ecological stability and deal adequately with the problems.

To achieve this blend, we need systematic, practical efforts to integrate agriculture, animal husbandry, and forestry. Moving from the qualitative understanding of the potential to a quantitative one, the work here with IITA and ILCA is clearly an example of the efforts we believe are necessary. Agroforestry is a technology we may clearly employ in addressing these needs, but we must be mindful of the other dimensions that will be required if purposeful integration is to take place. I refer to the policy issue (e.g., land and tree tenure), the legislative framework (the present overly conservative forestry codes that inhibit popular participation in tree planting), the administrative structure (e.g., how to organize agroforestry outreach programs to service the farmers), the economic aspects (farm income distribution and equities), and the social and cultural issues (who does the work, men or women?).

At USAID, we believe that farm forestry and agroforestry carefully and pragmatically put in place on the farms and farming lands of Africa can help address multiple facets of the development challenge we face in Africa: food production. This involves reversing deforestation, stabilizing and improving soils, and halting environmental degradation, and leads to the bright promise of socioeconomic development in the nations of Africa. I believe that the "Green Revolution" of Africa will be the green of the trees and crops in sustainable productive agriculture.

Special message

M. Peter McPherson

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As the administrator of the United States Agency for International Development (USAID), I am keenly interested in alley cropping. Slash-and-burn cultivation and bush fallow are two very significant development problems. Shortened rotation cycles and an increasing population farming a limited resource base on fragile lands have been major causes of growing environmental and social disaster. We are now seeing the dramatic effects in Africa, and elsewhere, of the loss of forest cover: soil erosion, desertification, and decreases of per capita food production. Alley cropping is an agroforestry technology that shows promise as one solution to this dilemma.

I am attracted to the potential of alley cropping. Therefore, I am most pleased to learn that IITA is taking the lead in formulating a plan to develop one or more collaborative networks for testing alley cropping on farmers' fields in different ecological zones in Africa.

I encourage increased collaboration between the agricultural research centres and donors, working with institutions in developing countries to develop viable alley cropping technologies. If we are to feed the world's growing population, we must increase and sustain agricultural production in underproductive and fragile environments where slash-and-burn cultivation is practiced.

I look forward to seeing the plan of action resulting from this workshop, a plan that will advance the technology of alley cropping for the benefit of all humanity. I wish you well in your deliberations over the next 5 days.

Part 2

Alley Cropping and Farming: an Overview

Alley cropping for food crop production in the humid and subhumid tropics

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Abstract — Upland arable farming on fragile, tropical soils requires viable, sustainable, and environmentally sound production systems that can meet the requirements of farmers who use traditional cultivation practices. Alley cropping, a scale-neutral technology, offers one of the best potentials for sustainable agriculture. Trials where various crops were grown between Gliricidia sepium *and* Leucaena leucocephala *tree rows in the lowland humid and subhumid tropics on nonacid soils have shown good results. Prunings from selected leguminous woody species such as* Leucaena *and* Gliricidia *give high nitrogen yield; these species also assist nutrient cycling. Prunings from woody species can also improve and maintain the organic matter, nutrient status, and biological activity of the soil. Results from long-term plots showed that maize yield was higher in alley-cropping plots than in control plots, even with the application of nitrogen.* Cassia siamea *and* Acioa barterii *are promising crops for alley farming on acid soils. The inclusion of hedgerows reduced runoff and erosion. Mechanized alley cropping is feasible if managed properly.*

Introduction

An urgent challenge facing agricultural scientists working on upland food-crop production in the humid and subhumid tropics is the need to find viable, sustainable, and environmentally sound alternatives to the centuries-old shifting cultivation and bush-fallow, slash-and-burn cultivation system. The traditionally extensive system of food-crop production, which is known to be stable and biologically efficient, operates effectively only when there is sufficient land to allow a long fallow period to restore soil productivity, which is exhausted during the short cropping cycle.

Over the years, however, this system has undergone rapid changes because of socioeconomic factors, mainly population growth, which has reached alarming rates in many developing countries in the last few decades (McNamara 1984). The population growth has put severe pressure on the availability of fallow land and has led to increased deforestation. For example, it is estimated that the closed forest area in the coastal zone of West Africa was disappearing at a rate of 5.1% (703×10^3 ha) per year during the early 1980s, mainly for agricultural production. At this rate, these forests have a half-life of just 13 years (Brown and Wolf 1985).

As productive land becomes scarce, smallholders are compelled to exploit more fragile, marginal lands that cannot support a large population practicing subsistence agriculture.

Deforestation and increasing population together have forced traditional farmers to shorten fallow periods, setting in motion a spiral of degradation resulting in lower crop yields, a trend noticeable throughout the tropics, particularly in Africa. Overgrazing and indiscriminate fuelwood gathering further intensify the problem of land degradation. Kio (1982) mentioned that fuelwood and charcoal account for more than 90% of wood consumption in Africa. According to a recent report from the World Resources Institute (WRI 1985), this situation, which prevails in many developing countries, can only be changed if rural populations are given alternatives to this ecologically destructive way of life.

Modern technologies adopted from temperate-zone agriculture to increase food-crop production under continuous cultivation have not always been successful on fragile, upland soils. The rapid decline in the productivity of tropical soils under continuous cultivation, even with supplementary fertilization, has been documented (Allan 1965; Bache and Heathcote 1969; Le Mare 1972). The failure of various mechanized arable farming methods (Duthie 1948; Wood 1950; Baldwin 1957; Phillips 1960; Moormann and Greenland 1980) highlights the need for a different approach for continuous arable farming on low-activity, clay (LAC) soils (Kang and Juo 1983). Lal (1975) stressed the importance of mulching and minimum tillage to maintain the physical productivity of soils. However, it appears that a more important factor in the maintenance of soil productivity is the biological manipulation of soil organic matter. This can be done through a planned fallow system providing adequate in-situ mulch and green manure (Hartmans et al. 1982; Mulongoy and Kang 1985).

Because the bush-fallow system is widespread and important to the livelihood of so many people (Nair and Fernandes 1984), it will be virtually impossible to dispense with it completely. This system, in addition to its main role of restoring soil fertility and suppressing noxious weeds, provides staking material, firewood, browse, and other materials needed by traditional farmers. There is, therefore, a need to develop technologies that can improve, reduce, or eliminate the bush-fallow period as well as retain its merits. This need has led to the development of alley cropping (Kang et al. 1981; Wilson and Kang 1981).

Alley cropping system

The bush-fallow system, despite its merits, has two main weaknesses: the extravagant use of land resources and the prolonged unproductive fallow. Young and Wright (1980) showed the need for long rest periods to maintain the productivity of fragile, tropical soils. The maximum acceptable ratio of cultivation to rest period ranges from 1–2 in every 20 years for Latin America to 1 in every 4 years in Asia and Africa for Ultisols and Oxisols. For Alfisols, it is about 1 in every 3 years. This need for a rest period can be reduced by the addition of fertilizers.

A major land-use problem in Africa and other tropical regions is the long, unproductive fallow needed to restore soil fertility (Poulsen 1978). The alley cropping concept for soil improvement, which emerged from work at the International Institute of Tropical Agriculture (IITA) with woody legumes during the early 1970s, was designed to allow a higher intensity of land use while maintaining the basic merits of the bush-fallow system (Kang et al. 1981). In alley cropping, arable crops are grown between hedgerows of woody shrubs and tree species, preferably legumes, that are periodically pruned to prevent shading of the companion crop(s). The shrubs and trees grown in hedgerows retain their functions as observed in the bush-fallow system, i.e., nutrient recycling, mulch and manure source, weed suppression, and erosion control (Fig. 1). The inclusion of leguminous, woody species also provides free nitrogen to the production system. Alley cropping can, therefore, be regarded as a bush-fallow system with improved management (Table 1), combining cropping and fallow phases to increase the land-use intensity.

To test the viability of the alley cropping concept, a long-term field trial with food crops and *Leucaena leucocephala* was carried on a degraded Entisol at the IITA main campus in 1976. Encouraged by the promising results obtained in this trial, further alley cropping trials were carried out using other woody species and crops at the IITA Ibadan campus and the Ikenne and Onne substations. Alley cropping is also being evaluated in a range of tropical environments under other names such as hedgerow intercropping (Torres 1983) and avenue cropping (Wijewardene and Waidyanatha 1984). On-farm trials were also carried out during the early 1980s in south and central Nigeria using *L. leucocephala* and *Gliricidia sepium*. The initial on-farm trials used narrow, 2-m alleys primarily for yam staking (Ngambeki and Wilson 1984). Although farmers accepted the merits of alley cropping, they felt that a 2-m alley was too narrow. This led to the use of 4-m alleys in subsequent on-farm trials. The incorporation of small ruminant production by the International Livestock Centre for Africa (ILCA) into the alley cropping system, using supplementary browse produced from the hedgerows on a cut-and-carry basis, has led to the development of the alley farming concept (see Reynolds and Atta-Krah, this volume).

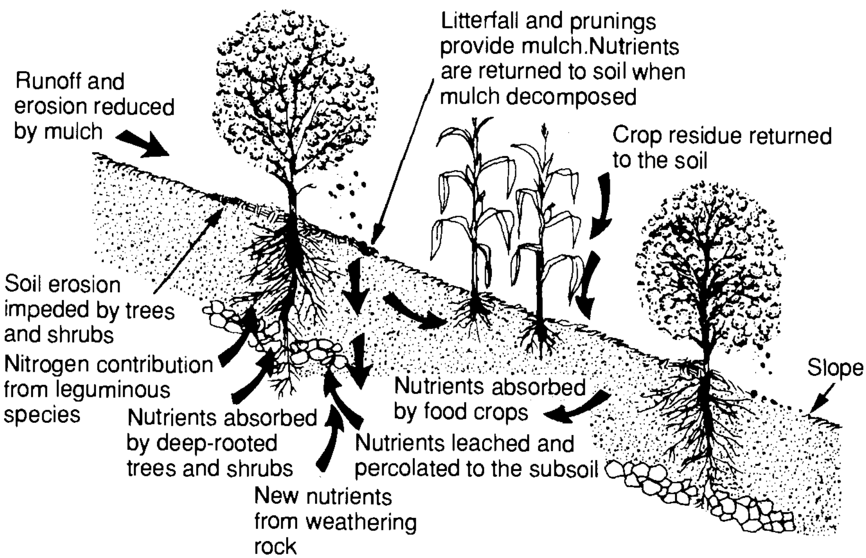

Fig. 1. The alley cropping concept.

Table 1. Differences in management of traditional bush fallow and alley cropping system.

Bush fallow	Alley cropping
• Retain mixed native and woody species	• Plant selected woody leguminous species
• Irregular planting pattern	• Grown in hedgerows
• Before cropping, trees and shrubs are cut back and burned to release nutrients	• Trees and shrubs are periodically pruned; pruning used as mulch and green manure
• Fire used for controlling growth	• Hedgerows are periodically pruned
• Allows short-term cropping	• Allows continuous cropping

Nutrient yield

The importance of forest and savanna fallow in building up soil nutrients through the development of a closed nutrient cycle is well known. This restorative role of the fallow is linked to the ability of deep-rooting trees and shrubs to recycle plant nutrients and build up soil organic matter. Jaiyebo and Moore (1964) have demonstrated that a forest fallow is more effective than legume or grass cover in nutrient recycling and organic matter improvement. Traditional African farmers retain certain woody species that are effective in restoring soil fertility during the fallow period. These species include *Alchornea cordifolia*, *Acioa barterii*, *Anthonata macrophylla*, *Harungana madagascariensis*, *Dialium guineense*, *Crestis ferruginea*, and *Nuclea latifolia* for acid soils (Obi and Tuley 1973; Okigbo 1976) and *G. sepium* for nonacid soils (Getahun et al. 1982).

Efforts have been made to improve the efficiency of the fallow by using woody species that can accelerate nutrient buildup. Nye and Stephens (1962) reported that *A. barterii* used as planted fallow accumulates more calcium and magnesium than natural secondary forest. Juo and Lal (1977) reported that *L. leucocephala* fallow is as effective as naturally regenerated fallow in restoring soil organic matter and exchangeable cations. Nye (1958) observed that, in the savanna region of northern Ghana, *Cajanus cajan* planted at close spacing accumulates larger quantities of nutrients than a well-established *Andropogon*. In northern Brazil, Schaafhausen (1966) claimed to have obtained good results in using *C. cajan* for soil improvement and as a source of fodder.

Kang et al. (1981) and Kang and Duguma (1985) have shown that leguminous species such as *L. leucocephala* and *G. sepium* grown in hedgerows in alley farming systems yield large quantities of nitrogen; the narrower the alley, the higher the nitrogen yield. With 4-m alleys and five annual prunings, *Leucaena* and *Gliricidia* grown on degraded Alfisol produced over 210 and 110 kg N/ha per year, respectively. Duguma (1985) showed that higher N yields could be obtained with higher pruning height and lower pruning frequency.

Table 2. Annual nutrient yield (kg/ha) of hedgerow prunings (4 m between rows, exclusive of woody material) of four fallow species alley cropped on a degraded Alfisol in southern Nigeria.

Species	P	K	Ca	Mg
Acioa barterii	2.0	19.7	12.3	1.9
Alchornea cordifolia	7.0	55.7	42.1	8.3
Gliricidia sepium	10.6	253.4	73.7	15.7
Leucaena leucocephala	14.6	192.8	114.9	10.7

Note: Yields measured in 3rd year after establishment; total of five prunings.
Source: B.T. Kang, unpublished data.

Prunings from hedgerows, which produced large quantities of biomass (Kang et al. 1981; Atta-Krah et al. 1985), also helped in recycling large quantities of other plant nutrients (Kang et al. 1984). Studies on a degraded Alfisol showed a higher nutrient yield (Table 2) than on a degraded Entisol (Kang et al. 1984).

Leucaena and *Gliricidia* give the largest nutrient yield. Indigenous, nonlegume shrub species of *Acioa* and *Alchornea* show lower nutrient recycling capabilities and yields.

There are large differences in nutrient percentage of the woody material of various species (Table 3). The high nutrient yields obtained from prunings can greatly assist in nutrient recycling in alley cropping systems. However, it can also impoverish the soil in a cut-and-carry system, if no nutrients are added to the production system. As stated by Benge (1983), woody legumes as with any other trees, require proper nutrition to maximize production and sustain yields.

Crop production

Crop performance

The performance of maize, cassava, and cowpea in alley cropping systems with *Leucaena* and *Gliricidia* has been widely studied on high base status soils in the humid and subhumid lowland tropics of Africa (Kang et al. 1984; Atta-Krah et al. 1985). Higher maize and cassava yields were obtained with alley cropping. From results of investigations conducted on an Entisol, it is estimated that *L. leucocephala* in alley cropping can contribute about 40 kg N/ha to the companion maize crop (Kang and Duguma 1985). Ngambeki (1985) also reported substantial savings in the use of nitrogen fertilizer when alley cropping *Leucaena* with maize. However, *Leucaena* either has no effect or a detrimental effect on cowpea grain yields (Kang et al. 1985; Atta-Krah et al. 1985). In investigations conducted on an Alfisol at Ikenne in southwestern Nigeria, it was observed that upland rice could be alley cropped with *Gliricidia* (Fig. 2) and *Leucaena*. Alley cropped with *Leucaena*, rice did not respond to nitrogen application. In the control plot, however, rice responded to an application of 30 kg N/ha.

Trials carried out in per-humid conditions at Onne in southeastern Nigeria

Table 3. Nutrient composition of "young" and "old" woody materials of various multipurpose tree and shrub species grown on Alfisol.

Species	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn (ppm)
Acioa barterii						
Young, green stem	0.59	0.08	0.66	0.49	0.11	20
Mature stem	0.55	0.07	0.57	0.30	0.14	16
Old wood	0.36	0.05	0.48	0.21	0.10	11
Alchornea cordifolia						
Young, green stem	1.12	0.18	1.83	1.19	0.22	36
Mature stem	0.65	0.11	1.42	—	—	18
Old wood	0.61	0.70	0.83	0.96	0.13	16
Gliricidia sepium						
Young, green stem	1.58	0.32	1.83	0.77	0.19	31
Mature stem	1.13	0.08	1.31	1.14	0.10	17
Old wood	1.01	0.05	0.87	0.97	0.12	13
Calliandra calothyrsus						
Young, green stem	1.98	0.19	2.32	0.63	0.22	37
Mature stem	0.95	0.20	1.33	0.26	0.08	24
Old wood	0.70	0.16	0.94	0.29	0.06	19
Leucaena leucocephala						
Young, green stem	1.38	0.14	1.78	0.91	0.27	32
Mature stem	0.71	0.06	1.02	0.49	0.11	31
Old wood	0.51	0.03	0.59	0.32	0.07	9

Source: B.T. Kang and H. Grimme, unpublished data.

showed poor performance of *Leucaena* and *Gliricidia* in the highly acidic Ultisols. Investigations were therefore carried out to identify suitable woody species for alley cropping on acid soils. Recent trials showed improved cassava yield when intercropped with *C. siamea* and *A. barterii* (Table 4). These investigations are still in progress.

An important aspect of alley cropping is its effect on the sustainability of crop yield (Kang and Duguma 1985) and the role it can play in the improvement of degraded soil and land (IITA 1985). Kang and Duguma (1985) reported a higher maize yield in long-term alley cropping plots than in control plots, even with nitrogen fertilizer application. This result has been confirmed by a long-term alley cropping trial carried out on a degraded Alfisol (IITA 1985). The higher maize yield may be partly due to improved and maintained chemical, physical, and biological soil conditions through the addition of the prunings.

Effect on soil properties

Long-term studies have shown significant improvement in soil properties with alley cropping (Kang et al. 1984). The periodic addition of *Leucaena* prunings helps maintain high soil organic matter and nutrient status. Observations on

Fig. 2. Alley cropping upland rice.

degraded Alfisol at Ibadan in southwestern Nigeria have also shown earlier and increased earthworm activity during the rainy season as measured by wormcast production in the alley cropping plots.

Planting trees on critical land can also play a significant role in soil conservation. Using *Leucaena*, Metzner (1982) significantly improved and maintained the productivity of degraded and sloping lands on the island of Flores in Indonesia. Recent studies by Kabeerathumma et al. (1985) in Kerala, southern India, have also shown a remarkable reduction in runoff and soil erosion with the inclusion of *Leucaena* in a cassava plot (Table 5). Similarly, in experiments at IITA with mechanized alley cropping on degraded land following bulldozer clearing, root raking, and conventional tillage, the land stabilized and improved compared with an adjacent plot that was shear-blade cleared and continuously cropped under no tillage.

Mechanized system

Alley cropping was originally developed for traditional farmers. In the course of investigation, however, it was observed that alley cropping could also be used as a scale-neutral technology. For this purpose, observations were made on two fields of over 2 ha each. Plots were planted with *Leucaena* by direct seeding together with a maize crop in 1983. The hedgerow spacing was 4.5 m to fit the machinery available at IITA. The plots were sequentially cropped with maize and cowpea.

Hedgerows must be frequently pruned in a mechanized system to prevent reseeding and prevent the stems from becoming too thick, which would interfere with future mechanical pruning. A rotary slasher is used to prune the hedgerows to ground level before planting maize or cowpea. The hedgerows are slashed again

Table 4. Effect of alley cropping cassava with various woody species on Ultisols at Onne, Nigeria.

Species and treatment[a]	Fresh cassava yield (t/ha) Stem	Tuber
Control		
No fertilizer	7.3	14.2
Fertilizer	10.4	16.0
Acioa barterii		
Prunings only	11.4	15.0
Fertilizer only	15.3	20.1
Prunings + fertilizer	15.0	16.0
Gmelina arborea		
Prunings only	4.1	5.4
Fertilizer only	2.3	3.5
Prunings + fertilizer	5.2	6.9
Cassia siamea		
Prunings only	7.0	13.2
Fertilizer only	6.7	10.7
Prunings + fertilizer	9.2	17.2

Note: Cassava was harvested 9 months after planting.
Source: B.T. Kang, A.C.B.M. van der Kruijs, and P.D. Austin, unpublished data.
[a] Control cassava stand, 10 000 plants/ha; other treatments, 6 667 plants/ha. Fertilizer rate, 30–13–25 kg/ha (N–P–K).

Table 5. Surface runoff and soil loss under various multiple cropping systems on an 8.9% slope in Trivandrum, India, from July to December.

Treatment	Runoff (mm)	Soil loss (t/ha per 6 months)
Bare fallow	21.6	2.37
Cassava	12.4	0.85
Banana	11.0	0.75
Eucalyptus	11.5	0.73
Leucaena	12.6	0.53
Banana + cassava	8.1	0.33
Eucalyptus + cassava	7.8	0.33
Leucaena + cassava	9.2	0.25

Note: Total rainfall from July to December, 252 mm.
Source: Kabeerathumma et al. (1985).

before harvesting the food crops, using a tractor with a 1.5-m wheel track and narrow tires. With 4.5-m spacing between hedgerows, however, only two-thirds of the land was effective for planting. A wider spacing of 7.5 m would be preferable, reducing the amount of land devoted to the hedgerows.

Soil conditions appear to improve under alley cropping, allowing continuous cropping. Sustained yields will compensate for a reduction in yield. Costs of pruning for the hedgerow can be reduced using machinery. Navasero (IITA 1984) showed that it took 6.7 h to slash 1 ha of 4 m wide hedgerows of *Leucaena* with a brush cutter; the same task took 37 h when manual pruning was performed with a thick-blade cutlass. Results of the 3-year observations have shown that mechanized alley cropping is feasible.

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Alley farming with livestock

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Abstract — *Alley farming is an ecologically sound, low-input farming system that links crop and livestock production.* Leucaena leucocephala *and* Gliricidia sepium *have been managed for mulch to sustain and improve crop yields and for fodder in a cut-and-carry system to raise livestock productivity. The competing demands of crops and livestock for tree foliage from alley farms is considered and the inclusion of a grazed fallow in the system is also discussed. A more intensive system of tree production to provide animal feed is described. On-farm trials in southern Nigeria have demonstrated that alley farming is appropriate and acceptable to small farmers.*

Introduction

The causes of failure in agricultural development efforts are as varied as the projects themselves; however, a single common factor can often be identified. Technically feasible and manageable interventions developed by research workers have failed to survive transference to the village environment. The common fundamental weakness has been the failure to understand the farming system and constraints imposed in the social context of the village community. Fertilizers, herbicides, and veterinary products are often difficult for small farmers to obtain, and research workers must consider the availability of off-farm resources when devising interventions.

Research with a farming-systems perspective is designed to ensure that interventions are relevant to the community for which they are intended. There are many variations of the basic farming systems research cycle of on-station trials; on-farm, researcher-managed trials; and, finally, farmer-managed trials. The Humid Zone Programme (HZP) of the International Livestock Centre for Africa (ILCA) has followed five stages:

- baseline studies to understand the farming system;
- identification of constraints;
- identification of possible solutions;
- testing solutions on-station and on-farm; and
- feedback and modification of interventions.

During the initial phase of a project, emphasis has been placed on understanding the farming system while identifying constraints; the devised solutions should, therefore, be relevant and appropriate. Interaction between on-station and on-farm research is an essential component of the ILCA strategy. Involving and training extension staff in on-farm work at an early stage are also important to ensure a gradual, smooth transition from research to extension under the control of national agencies. The HZP team consists of an animal scientist, a veterinarian, an agronomist, an agroforester, and a socioeconomist to meet the multidisciplinary requirements of farming systems research.

Alley cropping was developed in the mid-1970s in Africa by the International Institute of Tropical Agriculture (IITA) as an alternative to shifting cultivation (Kang et al. 1984). ILCA extended the concept to include livestock by using a portion of the foliage for animal feed in a cut-and-carry system, calling the resultant package alley farming (Okali and Sumberg 1985). This paper concentrates on the integration of livestock in alley farming and the related research activities of ILCA.

Farming systems in southern Nigeria

Farming systems have been studied in two diverse regions: southwestern and southeastern Nigeria. The dominant farming system in both regions is shifting cultivation. In some areas, increasing human population and demand for land have resulted in a shortening of the traditional fallow period, with a consequent progressive decline in soil fertility and crop yields. Maize, cassava, and yam are the major food crops and livestock production is a minor farm enterprise, contributing around 5% of total farm cash income. Small ruminants predominate, averaging two to four animals per household.

In the southwest, farmers cultivate several small fields for 4 or 5 years before allowing a roughly equal length of time for fallow. Farmers in the forest zone regard a fallow period as more necessary than those in the derived savannah (B. Herren-Gemmil, personal communication). Animals roam freely around the household area, feeding on natural vegetation, household wastes, and food processing by-products (Carew 1981; Sempeho 1985). Land availability is generally not a constraint to farming and fields are separated from the household by an uncultivated ring of land through which animals do not pass.

In the southeast, however, where the human population density is higher, land availability is limited, farm size is generally smaller, and animals are confined or tethered around the household to avoid damaging growing food crops in compound farms (Mack et al. 1984). The farmer is responsible for providing animal feed, usually browse from the bush, crop residues, household wastes, and food processing by-products. The most common by-product used as animal feed is cassava peel. The productivity of confined and tethered goats in the southeast is lower than that of their free-roaming counterparts in the southwest (Adeoye 1985).

Constraints

Shorter fallow periods are accompanied by declines in soil nutrient levels and crop yields. This can be overcome by land-use systems that permit a more rapid recovery of soil fertility and eliminate or minimize the need for long fallows. Crop production is the major farming activity and, while it remains a minor enterprise, farmers are unlikely to invest large amounts of time, land, or money to improve livestock production. Technologies that integrate benefits to soil fertility and crop production and simultaneously provide additional animal feed are more attractive.

The primary constraint to livestock performance is high mortality during the 1st year of life. "Peste des petits ruminants" (PPR) was identified as a major problem and a solution using tissue culture rinderpest vaccine (TCRV) was implemented (Opasina 1984). Feed quality and quantity, particularly for confined and tethered animals in southeastern Nigeria, was the second most important factor. In the southwest, food quality is poor during the dry season and, with a decrease in the mortality rate from PPR, the increased livestock population is expected to put pressure on food availability. Undernourished animals are always more susceptible to disease; therefore, a search for a low-input, year-round source of high-quality animal feed was undertaken.

Possible solutions

Pasture establishment, with and without herbaceous legumes, was considered but soon rejected because of land and management requirements and disease problems for both legumes (anthracnose) and animals (worms). Attention then focused on tree legumes that IITA had shown could improve soil fertility and crop production (Kang et al. 1981; Wilson and Kang 1981). The objective was to derive systems to maintain soil fertility during cultivation, eliminate the long fallow required in traditional farming systems, and release land tied up in fallows for continuous cultivation with sustainable yields. However, leguminous trees could also provide foliage for animal feed, thus allowing farmers to alleviate the nutritional stress on their livestock during the dry season.

In southwestern Nigeria, sufficient land would be available for the farmer to establish alley farms large enough to provide supplementary feed throughout the year. This would not be the case in the southeast because farms are smaller; consequently, a more intensive use of the trees (requiring less land) was devised. This system, called an intensive feed garden (IFG), envisaged a small plot (10 × 20 m) of closely planted trees intersown with grass, close to the house, providing readily available supplementary feed.

The most promising leguminous trees from IITA studies directed toward soil fertility and crop production were *Leucaena leucocephala* and *Gliricidia sepium*. A combination of these trees planted in alley farms and IFGs could allow mixed foliage to be offered to livestock. This would minimize the possibility of toxicity from high levels of *Leucaena* intake that might occur if farmers had only this one tree species available. *Gliricidia* is less productive than *Leucaena*; however, no problems of toxicity associated with *Gliricidia* have been observed. These two species could complement each other and be highly compatible in fodder-production systems. Alternate rows of the two species could be pruned 5 or 6 times/year when the regrowth reaches about 1.5 m. Tree foliage for animal feed could be used in a cut-and-carry system. Farmers would have the options of using varying proportions of the foliage for mulch or for animal feed. It was expected that mulching would be most important during the wet season and that a higher share would go for animal feed during the dry season.

There would be no cash cost to the farmer, no material to purchase, and no credit to repay. During the on-farm testing and development phase, seeds and advice would be provided by ILCA and the farmer would contribute land and labour. Labour would be the only recurrent input required from the farmer.

On-station trials

A comparison was made of 25 leguminous browse species including *Leucaena* and *Gliricidia*. The desired qualities were ease of establishment, strong growth and regrowth, persistence, palatability, and high quality as animal feed. Of the species tested, *Leucaena* and *Gliricidia* were most productive and *Leucaena* was more palatable than *Gliricidia*. With a crude protein content of over 20% and green forage production throughout the year, both species were sufficiently attractive to warrant further investigation.

Few studies had been made of *Gliricidia*. In 1983, ILCA collected 49 accessions of *Gliricidia* from Central America in collaboration with the Tropical Agriculture Research and Training Centre (CATIE, Turrialba, Costa Rica). From these, four high-yielding lines were selected that were more productive than the *Gliricidia* found in the Ibadan area (Sumberg 1985). Traditionally, *Gliricidia* has been established from stakes, but this had two disadvantages. First, shallow rooting trees were easily pushed over by grazing animals and suffered water stress in the dry season. Second, around 25 t of stakes were needed to establish 1 ha of alley farm with tree rows 4 m apart. Seed collection had not previously been considered because, on drying, mature pods spring apart, scattering the seeds. Pods were collected before they had dried on the tree and the seeds were found to germinate well. *Gliricidia* was subsequently established by seed. Comparisons of stake- and seed-established *Gliricidia* showed that, after 2 years, seeded trees were as productive as staked trees.

The importance of arable crop farming relative to livestock production in the Ibadan area suggests that positive returns to crop production through alley farming will enhance the acceptability of the system. In the traditional farming system, cropping for several years in succession results in a decline in crop yield as the nutrient content of the soil falls. Research at ILCA has confirmed the results of similar trials at IITA (Kang et al. 1984), showing the superiority of crop production in alley farming as compared with conventional (nonalley) farming (Table 1). Tree prunings (leaves plus soft stem) contain 2.9% nitrogen, on a dry-matter (DM) basis. Tree rows 4 m apart and a tree spacing of 25 cm within rows gives an annual DM yield of around 6 t/ha, equivalent to 174 kg N/ha (Table 2). Applied to the surface, 1 kg of mulch N will produce approximately an extra 5 kg of maize grain; if it is incorporated into the soil, it will produce 10 kg of maize (Kang et al. 1981).

ILCA has assumed that the primary use for tree foliage will be to maintain crop yields, and that additional material can either be used as animal feed or to raise crop yields above the base level. A model based on experimental and field data to quantify the benefits of alley farming has been developed by Sumberg et al. (1985). If the base maize yield is 2 t/ha, decreasing annually by 20% because of less fertile soil, sufficient mulch N from trees to produce an additional 400 kg of maize would be needed to maintain the base level of production (i.e., 80 kg mulch N, at 5 kg maize/kg mulch N). On this basis, 2.8 t DM of tree foliage at 2.9% N would be

Table 1. First-season yields of maize grain (t/ha) in conventional farming and alley farming systems at Ibadan (1983–1985) in on-station trials.

	1983	1984	1985	Mean
Conventional cropping (no trees)	1.86	2.17	2.13	2.05
Continuous alley farming	2.17	3.06	2.41	2.55

Table 2. Yields of mulch dry matter (DM) and mulch nitrogen from *Leucaena* (planted in 1982) and *Gliricidia* (planted in 1983) in alley farming at Ibadan (1983–1985) in on-station trials.

	Leucaena		*Gliricidia*	
	DM (t/ha)	Nitrogen (kg/ha)	DM (t/ha)	Nitrogen (kg/ha)
1983				
First season	2.78	97	—	—
Second season	3.00	69	—	—
1984				
First season	4.19	112	3.05	104
Second season	2.19	54	2.83	83
1985				
First season	5.34	116	2.98	98
Second season	1.44	49	2.83	77
Annual mean	6.31	166	5.84	181

needed to maintain annual crop yields at 2 t/ha. With an annual foliage production of 6 t DM/ha, the surplus foliage, available either for mulch or feed, would be 3.2 t/ha.

Tree management will differ if the purpose is animal feed production rather than mulch. For mulch, trees can all be cut together; pruning for animal feed, however, must be staggered. Assuming a daily feed intake of 4% of body weight, a 15-kg goat needs 600 g DM/day. If supplementary browse from the tree provides 50% of daily intake, 300 g browse DM/head will be required daily. In this example, the surplus foliage from 1 ha could supplement 29 goats/year.

The inclusion of a 2-year fallow period in *Leucaena* alley farming has also been studied. Grazing animals could use the natural regrowth between trees during the fallow years. Goats were found to debark trees and so the study has concentrated on sheep. Bark damage has also been observed with sheep, however, and animal management has posed some problems. During the early rains, regrowth is vigorous and animals are not keen to enter the long grass – weed mixture, preferring to remain around the trampled, outer areas. Hand slashing was performed on the regrowth. Later in the year, tree growth shaded out many of the plants and, as there was little remaining on the ground for animal feed, *Leucaena* intake became a more important component of the diet and signs of mimosine toxicity became apparent. For these reasons, grazing of small ruminants in alley farms during the fallow period is not recommended.

When the grazed fallow plots returned to maize production, however, crop yields were 75% higher than yields from conventional continuously cropped plots and 30% higher than from continuously cropped alley farms (Table 3). It was impossible from this trial, however, to differentiate between benefits accruing from the presence of animals and those as a result of the fallow period. The effects of different lengths of cropping and fallow periods in alley farming deserve further study.

Preliminary observations have been made on tree and grass combinations designed to intensify animal feed production from a small area (10 × 20 m) for use in the highly populated areas of southeastern Nigeria. During the establishment year, foliage yield was higher (9.85 t DM/ha) with tree rows 4 m apart interplanted with four rows of grass in each alley. Crude protein yield (493 kg DM/ha) was higher with tree rows 2.5 m apart with two rows of grass. In year 1, IFG production from a 0.02-ha plot would be sufficient to supply 25% of the daily intake of 3.6 small ruminants. In year 2, the trees will be more productive.

The effect of interrow spacing in "tree-only" plots is also being studied, using spacings of 0.5 to 2.0 m. Yield per hectare during the establishment year is highest with tree rows 0.5 m apart. Duguma (1985) studied the effects of cutting height and cutting frequency of hedgerows. Raising the cutting height to 1 m above ground and decreasing the interval between cuttings to 6 months increased tree yield. During the wetter months from April to September, DM yield was almost twice that found from October to March. On-farm observations have shown that farmers do not return manure and feed refusals to the plots; therefore, the long-term effects of continuous removal of foliage on soil nutrients is being studied.

In addition to producing tree foliage and ascertaining the best on-station management routines, ILCA has also studied the effects of using mixed *Leucaena–Gliricidia* browse in a cut-and-carry animal production system. A daily intake of 450 g DM/head of supplementary browse by pregnant and lactating ewes

Table 3. Yield of maize grain (t/ha) during 1985 in conventional farming, alley farming, and alley farming after a 2-year grazed fallow at Ibadan in on-station trials.

Farming system	First season	Second season	Total
Conventional (no trees)	2.13	0.93	3.06
Continuous alley farming	2.41	1.70	4.11
Alley farming after fallow	3.30	2.04	5.34

increased the productivity index (kilogram offspring weaned per ewe per year) by 55% over those receiving the basal diet of *Panicum maximum* (Reynolds and Adeoye 1985). Although it is clear that *Leucaena–Gliricidia* browse increases livestock performance, it should be pointed out that the basal *Panicum* diet is of much lower quality than that obtained by free-roaming village animals. A productivity index of village sheep has been recorded at 10.3 kg offspring weaned/ewe per year (Mack 1983); this is equivalent to the index of on-station sheep consuming 270 g browse DM/head per day. The consumption of a further 180 g browse DM/head per day raised the productivity index by 20%, and there was no indication that incremental effects were declining.

Sheep showed signs of mimosine toxicity (i.e., loss of facial hair) when offered the high levels of browse. Group feeding was practiced, however, and individual dominant animals are suspected to have taken more than their share of *Leucaena*, which is more palatable than *Gliricidia*. In another browse-supplementation trial with individual feeding, no signs of toxicity were encountered, even though the quantities offered per head were the same as in the previous trial. The effects of rumen microbes able to detoxify mimosine will soon be studied in West African Dwarf sheep and goats.

On-farm trials

The target clients for alley farming and intensive feed garden interventions were farmers with access to land who preferred to keep small ruminants. Farmers did not need additional finances to establish alley farms, and credit facilities were not needed. ILCA provided advice and seeds for the trees but allowed the farmers to modify the interventions to suit their own circumstances. Trees were established under many combinations of food crops, and, by observation, it was discovered that planting with first-season maize produced the strongest trees. Mature cassava gave too much shade and yam vines could smother the tree seedlings (see Atta-Krah and Francis, this volume). The number of alley farms increased from 2 in 1981 to 100 in December 1985, and another 40 farmers in nearby villages have requested seed to plant alley farms in 1986. The production of large quantities of *Leucaena* and *Gliricidia* seed will be a prerequisite to the expansion of alley farming under the auspices of national agencies.

An important component of the ILCA strategy has been feedback from on-farm to on-station work. In the establishment year, farmers planted trees into every fourth ridge of food crop. In the 2nd year after ridge splitting, trees remained in the furrow, with four ridges between tree rows. In subsequent years, however, the number of ridges made by farmers alternated from three to four between tree rows (Fig. 1). The effects of this are now being studied. Some farmers contracted for tractor ploughing and, in some cases, rows of trees were accidentally destroyed in year 1. To avoid this problem, farmers who intend to use tractors now plant tree rows 5 m instead of 4 m apart.

During the latter part of the rainy season, 25% of the farmers with 1-year-old trees were regularly providing mixed browse from the alley farms to their livestock. It was expected that more farmers would be feeding browse to their livestock during the dry season; however, this has not yet been observed.

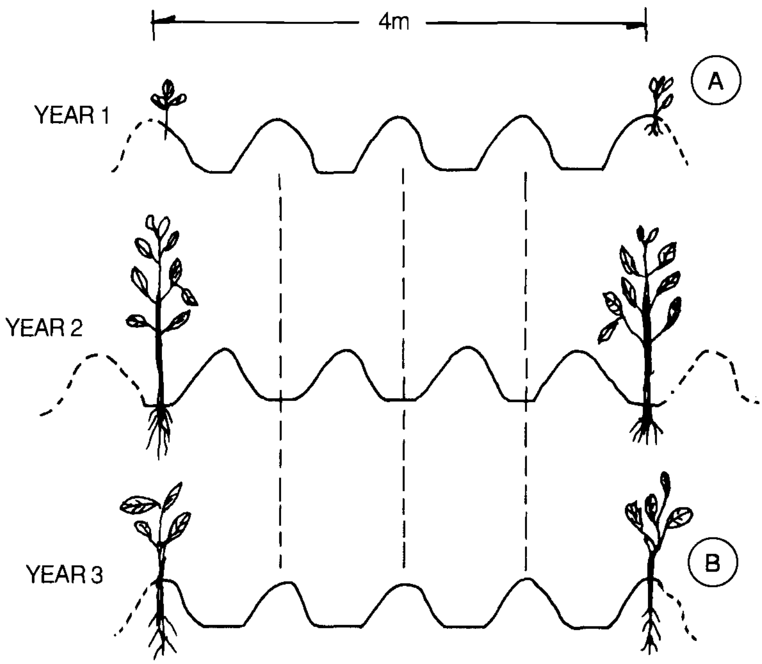

Fig. 1. Ridge movement in farmer-managed alley farms. A, tree seedling on same ridge as maize; B, tree.

Table 4. Distribution of free-roaming and restricted animals (% of households) in four states of southern Nigeria.

	Anambra	Imo	Rivers	Bendel
Restricted all year	65	38	11	9
Restricted only in cropping season	27	42	0	12
Free roaming	8	20	89	79

Source: Okali and Sumberg (1985).

In Anambra and Imo states in southeastern Nigeria, confining or tethering livestock for at least part of the year is required in 92 and 80% of households, respectively (Table 4). This development is relatively recent and farmers do not appear to have evolved suitable feeding systems for confined or tethered livestock. When ILCA began its trials on alley farming, it was uncommon for farmers to offer grass to confined or tethered livestock. The difficulty of providing feed from daily collections of browse in the bush was widely acknowledged by the farmer, and fodder trees were accepted as suitable for cultivation. Emphasis was initially placed on IFGs because of constraints on land availability as perceived from baseline studies. Almost as many farmers have chosen to plant alley farms, however, as have planted IFGs; consequently, the emphasis placed on IFGs in southeastern Nigeria is being reevaluated. Few farmers were able to allocate the 0.02 ha recommended for IFGs and much of the land used was only temporarily vacant, having been earmarked for other purposes in the near future. The average area of an IFG (0.01 ha) has proved insufficient to provide supplementary feed for two to four small ruminants (the average herd size) on a continuous basis throughout the year. Attention will be paid to strategic supplementation of pregnant and lactating female animals and to the provision of dry-season feed.

Conclusions

Improved agricultural production in Africa depends on the development of relevant technology and efficient transfer mechanisms to move such technology from the research stations to the farmer. Alley farming is a technology with a sound ecological base. Its emphasis on maintaining soil fertility and improving land use is appropriate for the humid and subhumid areas of tropical Africa where soils are generally highly weathered with inherent low fertility and low structural stability. Furthermore, the possibility of integrating a livestock component into the general farming system through alley farming opens a new area of crop–livestock interaction. Most farmers in the humid and subhumid tropics have both crop and livestock interests; however, in general, these interests are pursued independently. Alley farming has the potential to encourage the interaction between crops and livestock to the benefit of both components.

On-station trials have shown that crop yields can be maintained and improved using mulch from trees in alley farms. The inclusion of a fallow period in alley farming provides an additional boost to crop yields; further investigation of short fallow periods is required. Supplementation using tree foliage for small ruminants increases productivity by providing dietary protein; this is particularly valuable in the dry season for confined animals.

On-farm work in southern Nigeria has demonstrated that alley farming is appropriate and acceptable under village conditions. This intervention is of potential benefit to other areas of Africa; however, adaptations and modifications of the alley farming system in other countries to allow for particular local requirements must be studied.

National institutions should become more involved in research, development, and extension efforts to allow wider testing and adoption of alley farming. Training of national staff will be a prerequisite for this development, and ILCA is able to provide such assistance. Seed production on an expanded scale is also necessary and national institutions should be encouraged to establish their own production capability. To this end, superior tree species must be identified and tested locally.

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Alley cropping: potential for plantain and banana production

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Abstract — Plantains and cooking bananas are important carbohydrate food sources in the humid tropics. They are traditionally grown in bush-fallow rotational systems, multistory cropping systems, or backyard gardens. Mulching is shown to be beneficial for plantains and bananas. Alley cropping with leguminous trees and shrubs is proposed as a source of mulch. Three concepts for managing plantains with woody legumes are being tested.

Introduction

Plantains and cooking bananas (*Musa* spp.) are among the most important carbohydrate sources in the diet of people in the humid tropics; as such, they are integral components of most farming systems in this region (Wilson 1983). In research aimed at improving the productivity of cropping systems in the humid tropics, therefore, plantain and banana should receive attention relative to their importance.

If alley cropping (Kang et al. 1984) is to be considered as an alternative to shifting agriculture, then its compatibility with the major crops (e.g., plantain and banana) must be determined. It is important to emphasize that plantain and banana are being discussed here in the context of small farm production systems that are basically biological, with trees and microorganisms being the system's effective restorers of soil fertility and productivity.

Production systems

Plantains and cooking bananas are produced in areas where the mean minimum temperature is above 15.5°C and rainfall usually exceeds 2000 mm, with fairly uniform distribution throughout the year and no distinct dry period (Simmonds 1966). Most *Musa* species are shallow rooted and thus need a good supply of moisture in the upper soil layer. This shallow rooting is also responsible for lodging and, therefore, windbreaks and props are required.

The only major factor limiting the type of soil in which these crops will thrive is good drainage. They need a high soil moisture content but will not tolerate flooding or stagnant conditions (Simmonds 1966). Plantain is dominant in the humid lowlands of West and Central Africa and cooking banana occupies large areas of the cool highlands of East Africa. There are three major production systems:

- shifting cultivation or bush-fallow rotation where plantain is usually combined with other crops;
- multistory complexes with plantain occupying an intermediate canopy level between trees and food crops such as maize, cassava, and cocoyam; and
- intensively managed, compound or backyard gardens where soil fertility is maintained at a high level with household refuse and animal waste.

In the shifting agriculture and bush-fallow rotation systems, a short cropping period rotates with a long resting period or fallow in which the land is recolonized by a random succession of plant species. The length of fallow depends on the time required to restore the soil fertility, the species in the recolonizing sequence, and the crops cultivated. In this system, which is widely practiced in West and Central Africa, plantain may be the first or last crop in the sequence after the land recovers from the fallow. Plantain may remain in the field for many years; however, in most small holdings, it is managed only in the 1st year. For reasons not yet understood (Braide and Wilson 1980), this system is marked by a rapid decline in yield after the 1st year. A common modification of this system is growing plantain in the "taungya" system, where farmers plant food crops (including plantain) on land cleared for reforestation and care for the young trees as they care for the food crops.

The multistory system seems to have evolved from the bush-fallow system under upland conditions where population pressure eliminates the fallow. Trees occupy the upper canopy level, plantain or banana occupies the middle canopy level beneath the trees, and shorter food crops such as roots and tubers, legumes, grains and vegetables occupy the lower canopy level. In parts of Asia, the Caribbean, and Latin America, coconut dominates the top level. In West Africa, oil palm occupies this level. In East Africa, banana occupies the top level, with roots and tubers, cereals, and legumes in the lower levels. These multistory systems are possible because plantains and bananas are tolerant to a certain amount of shading (Vincente-Chandler et al. 1966). Yield decline is not as rapid in the multistory system as in the bush-fallow rotation system.

The compound garden is the most productive system. It does not relate directly to human population density as it can be found in areas where both bush fallow and multistory cropping are practiced. This system occurs with banana in East Africa and with plantain in West Africa. The plots are usually small and close to the house, from which they receive organic refuse. This system, which is mostly organic, contributes not only nutrient and organic matter to the soil but also forms mulch, which may be an important factor in the productive longevity of plants in this system. These plots have been known to remain highly productive for many years (Braide and Wilson 1980; Swennen 1984). Mulching is beneficial to plantains and bananas and this, in turn, has led to attempts to develop feasible mulching methods (Wilson and Swennen 1986).

Of these three systems, only the intensively managed compound garden does not depend directly on trees to restore soil fertility, even though trees may be found within these gardens. Yet, it is these gardens that indicate a potential for alley cropping plantains because they show a response to mulch, which is one of the direct products of alley cropping.

Potential of alley cropping

Although the mechanisms of high productivity and extended longevity of plantains in home gardens are not well understood, there is convincing evidence that mulching and high soil organic matter are important contributors. Thus, in attempts to develop alley cropping systems to increase the productivity and production of plantain and banana, emphasis has been on mulch production. Besides covering the soil, the mulch should contribute reasonable amounts of organic matter and nutrients. In the alley cropping system, the mulch would be produced by trees. These trees would recycle nutrients and, in some cases, fix nitrogen. They can also be managed to serve as windbreaks or to produce stakes for bracing the plantain or banana. Both windbreaks and stakes would reduce wind damage, one of the major problems in the production of *Musa* spp. The microclimates created by the presence of trees in the field are expected to favour plantain and banana (Vincente-Chandler et al. 1966).

Three concepts of managing plantain with trees and shrubs in alley cropping are being tested:

- woody shrubs planted in rows between plantain, which are controlled so that plantains always occupy the upper canopy during the cropping period (Fig. 1);
- the upper canopy alternates between plantain and trees (Fig. 2); and
- the trees occupy the upper canopy level at all times (Fig. 3).

In the first concept, *Leucaena leucocephala* and *Flemingia congesta* are often planted in association with plantain. Both species appear tolerant to the shade from plantain and recover well after pruning. The leaves of *Leucaena* decompose rapidly

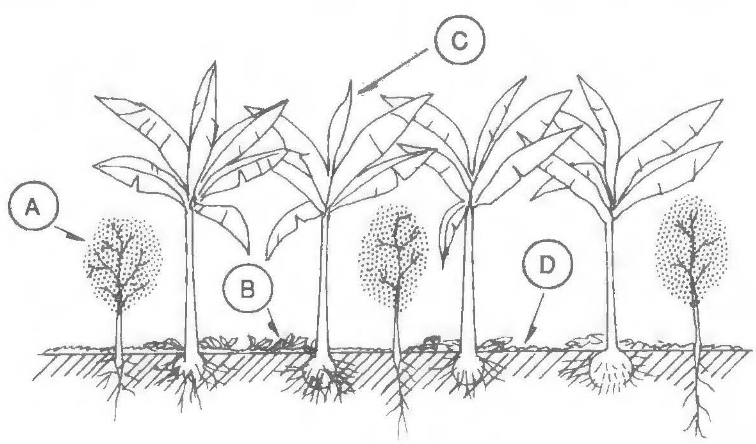

Fig. 1. Alley cropping with top of the hedgerow plants below the plantain canopy. A, hedgerow plant; B, leaf litter; C, plantain/banana; D, soil surface.

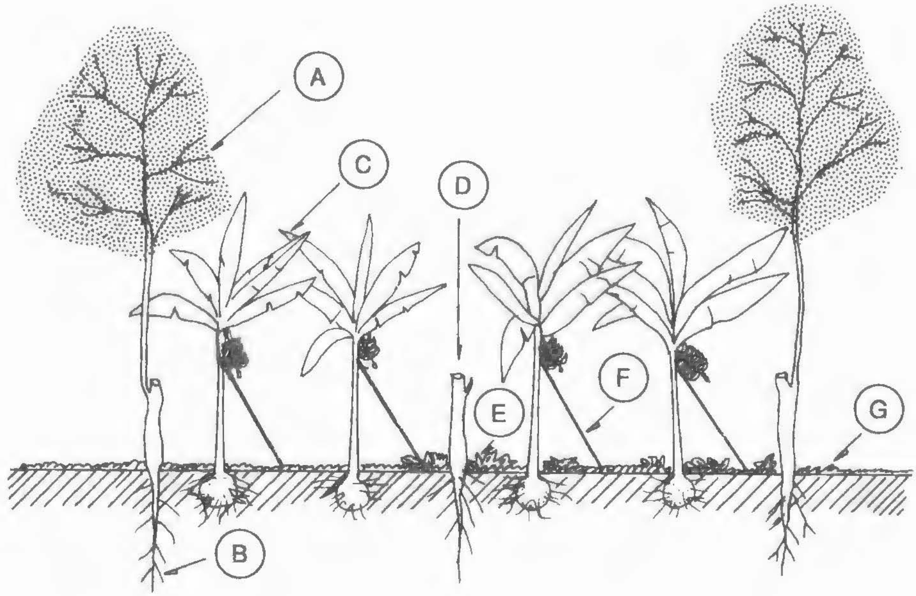

Fig. 2. Alley cropping with hedgerows, which provide poles, serve as windbreaks, and help to recycle nutrients. A, tall tree; B, deep roots; C, plantain/banana; D, cutback tree; E, leaf litter; F, support pole; G, soil surface.

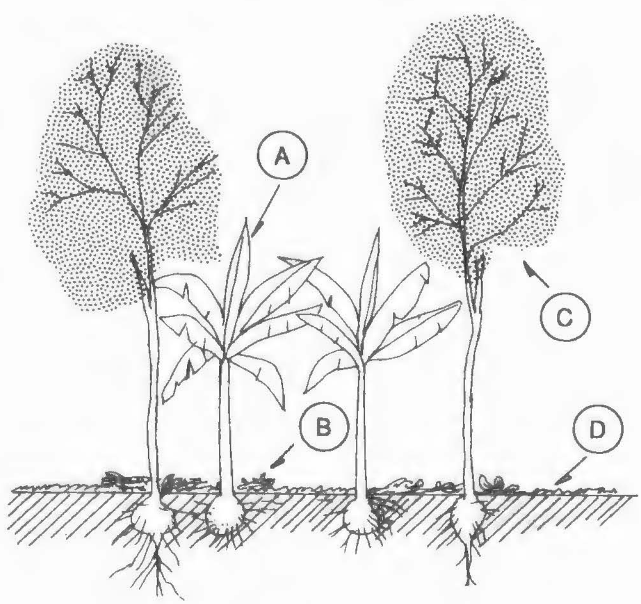

Fig. 3. Alley cropping with the hedgerow canopy above the plantain canopy. A, plantain/banana; B, leaf litter; C, hedgerow plant; D, soil surface.

and do not form a good mulch. However, the twigs persist long enough to provide surface soil coverage and slow the surface movement of water. The rows of trees planted along the contour help prevent rapid water flow. No significant erosion occurs when plantain is alley cropped with *Leucaena*. *Flemingia* leaves decompose more slowly than *Leucaena* and form a good mulch.

The second concept combines mulching, windbreaking, and propping (Fig. 2). The canopy levels of the trees and the plantain alternate as trees are cut back to provide mulch and stakes. The number of rows cut should be estimated from wind speed data. Harnessing plantains to the standing trees should also provide additional protection against wind damage. The deep roots of the trees aid in nutrient recycling.

The third concept combines mulching and windbreaking (Fig. 3). The tree canopy occupies the upper story at all times and periodical pruning of the trees is done at the level of the plantain canopy. Alternate-row pruning ensures the windbreak effect. Harnessing the plantain to the trees provides additional protection against wind damage.

In all three concepts, mulch has been emphasized; however, the nutrient contribution from the trees has not been overlooked. This contribution may not meet the total nutrient requirement for high yields, but it can substantially reduce the requirement for inorganic fertilizer.

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Part 3

Planted Leguminous Browse

Planted leguminous browse and livestock production

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Abstract — Browse is an important component of the diet of small ruminants under traditional management in southern Nigeria. The leguminous trees Leucaena leucocephala *and* Gliricidia sepium *planted in alley farms or intensive feed gardens can provide a high-protein supplement for use in a cut-and-carry system. The digestibility of browse dry matter increases when a high-energy supplement such as cassava peel is also offered. On-station trials have shown that a mixed* Leucaena–Gliricidia *supplement can raise the productivity of West African Dwarf sheep on a basal* Panicum maximum *diet by 55%. At the village level, small farmers with established* Leucaena *and* Gliricidia *have fed the foliage to their small ruminants. Strategic feeding to pregnant and lactating females and the use of fallow land within* Leucaena *and* Gliricidia *alleys for grazing and browsing animals are discussed.*

Introduction

Free-roaming livestock consume a wide variety of materials from grasses, herbs, shrubs, and trees. The selection made depends on plant availability, season, and the livestock species involved. Browse is more important in the diet of goats than in that of cattle; this preference for browse is even more marked in the dry season. Forage taken by farmers for cut-and-carry feeding is usually of lower nutritive value than that selected from the same area by browsing and grazing livestock because animals pick young shoots over more mature material. Browse maintains its nutritive value throughout the year; the nutritive value of grasses, however, declines rapidly after flowering. Leguminous species provide particularly valuable, high-protein feed that can complement low-protein cellulytic materials (e.g., mature grasses and crop residues).

Forage production from woody and herbaceous legumes has been studied by the Humid Zone Programme (HZP) of the International Livestock Centre for Africa (ILCA) at Ibadan, Nigeria. Anthracnose was found to be a serious problem with *Stylosanthes*, and woody legumes were considered to hold more promise for cut-and-carry feeding systems. Attention has concentrated on *Leucaena leucocephala* and *Gliricidia sepium*, the most productive of the 25 browse species studied.

Southern Nigeria accounts for about 9 million of the estimated 54 million small ruminants and 0.3 million of the estimated 42 million cattle of the humid and subhumid zones of tropical Africa (Jahnke 1982; ILCA 1985). There is an average of two to four small ruminants per household, and 87% of cattle are kept in herds of six or less. HZP has concentrated on small ruminants, reflecting their predominance in the region. Two distinct, local, management systems are employed for sheep and goats. In southwest Nigeria, animals roam free; in the southeast, however, where the human population density is high, tethering and confinement are practiced. In both systems, farm fields are small and scattered, and animal numbers are too small to warrant labour required for herding animals on fallow fields.

ILCA has studied the leguminous browse trees *Leucaena leucocephala* and *Gliricidia sepium* and their use in cut-and-carry feeding systems to supplement the traditional diet of small ruminants in villages (Fig. 1). Branches are cut at a length of around 150 cm. The effects of supplementation have been recorded in on-station trials, but relatively little work with small ruminants receiving *Leucaena* and *Gliricidia* has been reported from on-farm trials.

Composition of *Leucaena* and *Gliricidia*

Small ruminants consume leaves, petioles, and bark leaving only the bare, woody stems. Leaves, which account for 75% of the edible parts of both species (Table 1), are the most nutritionally valuable of the material consumed (Table 2). The high nitrogen content in leaves (around 3.2%) is the major advantage of *Leucaena* and *Gliricidia* as feeding materials.

Fig. 1. Farmer feeding goats with *Gliricidia*.

Under a pruning regime of six cuttings per year, fresh growth can be available throughout the year, ensuring a continuous supply of high-quality supplement. Browse can enhance the feeding value of low-quality roughage because additional protein can increase rumen microbial activity, thus improving the overall digestibility of the diet and increasing food intake.

Leucaena leucocephala

Leucaena has been the subject of many recent studies and its use as animal feed is well recognized (Gray 1968; Hill 1971; NAS 1977; Jones 1979). *Leucaena* is highly palatable but has the disadvantage of being toxic at high intake levels because of the amino acid, mimosine. Young shoots, which are more palatable than mature leaves, contain more mimosine than older foliage. Rumen microbes degrade mimosine to 3-hydroxy-4 (IH) pyridone (DHP), which is then absorbed into the bloodstream before eventually being excreted in the urine. DHP is goitrogenic and depresses serum thyroxine levels (Jones et al. 1976). Depressed appetite, low weight gain, and alopecia are early signs of toxicity. Ulceration of the esophagus may also occur. In Hawaii and Indonesia, urine from goats fed high levels of *Leucaena* was found to be free of DHP. The healthy appearance and good productivity of these animals led Lowry (1983) to suggest that they might contain

Table 1. Component parts (%) of the edible portion of *Gliricidia* and *Leucaena*.

	Gliricidia	*Leucaena*
Leaf	74.7	76.6
Petiole	9.3	11.7
Bark	16.0	11.7

Source: Mani (1984).

Table 2. Chemical composition (%, dry matter basis) of the edible parts of *Gliricidia* and *Leucaena*.

	Crude protein	Crude fibre	Ether extract	NFE[a]	Ash	ADF[b]	Lignin
Gliricidia							
Leaf	22.5	16.5	7.8	44.4	8.8	22.3	12.3
Petiole	8.1	32.5	2.0	47.3	10.1	49.1	12.7
Bark	12.2	30.5	4.0	41.7	11.6	38.1	15.6
Leucaena							
Leaf	18.3	22.4	12.0	37.9	9.4	20.5	9.7
Petiole	7.8	38.3	1.3	43.9	8.7	47.2	13.6
Bark	9.8	34.2	5.0	42.6	8.4	40.3	10.0

Source: Mani (1984).
[a] Nitrogen-free extract.
[b] Acid detergent fibre.

rumen microbes able to degrade DHP (Jones 1981). J.L. Lambourne, H.G. Bosman, and L. Reynolds (unpublished data) noted the presence of DHP in the urine of Nigerian West African Dwarf sheep and goats. This confirms deductions, based on field observations of alopecia, that sheep and goats in southern Nigeria lack detoxifying rumen microbes.

Jones et al. (1985) reported that rumen fluid from goats adapted to *Leucaena* diets can be transferred to unadapted animals, allowing the latter group to degrade DHP. Introduced bacteria can also be passed from animal to animal and will persist for at least 6 months after removal of the animal from *Leucaena* feeding. The National Academy of Sciences (NAS 1977) recommended restricting intake of *Leucaena* to below 30% in ruminant diets to avoid reactions. The availability of a rumen inoculum that can degrade DHP will allow higher levels of *Leucaena* to be offered safely. Preliminary results from Australia indicate that animals inoculated with detoxifying bacteria will perform better than those without the bacteria when offered moderate dietary levels of *Leucaena*.

Leucaena is generally offered as a component of the diet rather than as a sole feed because of the toxic effects. As shown in Table 3, the dry matter (DM) intake of a *Panicum–Leucaena* mixture increased as the proportion of *Leucaena* rose (Ademosun, Jansen et al. 1985); the same pattern was observed with maize stover – *Leucaena* mixtures (Banda and Ayoade 1985). Similar observations were made by Cochran et al. (1984) using maize stalks with *Leucaena* and by Wong and Devendra (1983) with *Pennisetum purpureum* and *Leucaena*; the proportions of *Leucaena* in the material eaten as opposed to that offered was not stated in both studies. Dry matter digestibility improved with increasing *Leucaena* intake (Ademosun, Bosman et al. 1985; Ademosun, Jansen et al. 1985), but the effects were less apparent in other studies.

Table 3. Daily dry matter intake (g/kg live weight$^{0.75}$) and digestibility (%) of diets containing *Leucaena*.

Diet	Animal[a]	Intake		Digestibility
		Leucaena	Others	
Leucaena + *Panicum*	WAD	23.5	40.8	51.1
Leucaena	WAD	—	48.3	47.5
+ *Panicum*		20.6	45.3	52.1
		10.7	39.6	39.8
		31.6	36.8	47.8
Leucaena	SEA	—	20.8	45.7
leaf hay +		11.0	20.7	50.9
chopped		21.2	20.5	48.0
maize stover		25.8	18.3	54.3

Source: Ademosun, Bosman et al. (1985), Ademosun, Jansen et al. (1985), and Banda and Ayoade (1985).

[a] WAD, West African Dwarf goat; SEA, Small East African goat.

Cochran et al. (1984) found that growth rates (28 g/day) in an 8-week trial where *Leucaena* was offered as 30% of the diet were higher than with 10% inclusion; however, above 30%, *Leucaena* did not give additional benefits. Wong and Devendra (1983) demonstrated increasing live-weight gains with up to 75% *Leucaena* in the diet, but the length of the trial was not stated. They indicated that a period of acclimatization to *Leucaena* may be necessary. Ademosun, Jansen et al. (1985) found little change in live-weight until goats had been on trial for around 44 days; however, over the following 112 days, the growth rate was 34.8 g/day (Ademosun, Bosman et al. 1985).

Gliricidia sepium

Gliricidia was originally introduced to West Africa to provide shade for cocoa trees; its distribution still largely reflects this role. It has also been used as a living fence post.

Gliricidia has been offered mainly in combination with other feeds (Table 4). As a sole feed, a DM digestibility (DMD) of 54–57% has been observed. The addition of an energy source such as cassava tubers (Ademosun, Bosman et al. 1985) or cassava peel (Ifut 1987), however, can raise DMD to 70–74%. Starch in cassava is fermented in the rumen to volatile fatty acids. These fatty acids are used by rumen microbes as an energy source for maintenance and growth, for which nitrogenous compounds are also required. A high-nitrogen feed such as *Gliricidia* will be used more efficiently when a fermentable energy source is also present (ARC 1980).

The inclusion of *Panicum maximum* in a *Gliricidia* diet in one study caused DMD to fall as the proportion of grass in the diet increased (Ademosun, Jansen et

Table 4. Daily dry matter intake (g/kg live weight$^{0.75}$) and digestibility (%) of diets containing *Gliricidia* fed to West African Dwarf goats.

Diet	Intake		Digestibility
	Gliricidia	Others	
Gliricidia	66.7	—	56.8
+ *Panicum*	56.8	13.8	57.5
+ Chopped cassava tubers	42.5	23.0	69.8
Gliricidia	—	43.1	46.0
+ *Panicum*	10.8	39.8	47.7
	21.3	38.1	51.1
	31.8	37.2	54.9
Gliricidia	46.4	—	54.2
+ *Panicum*	39.9	23.6	66.6
+ Cassava peel	28.2	47.7	74.3
+ *Panicum** and cassava peel**	21.0	11.7* 53.6**	71.9
	25.9	13.7* 32.9**	66.1

Source: Ademosun, Bosman et al. (1985), Ademosun, Jansen et al. (1985), and Ifut (1987).

al. 1985); however, with lower levels of *Panicum*, the digestibility was unchanged (Ademosun, Bosman et al. 1985) or improved (J.O. Ifut and L. Reynolds, unpublished data). With a combination of *Gliricidia*, *Panicum*, and cassava peel, DMD tended to decrease as the level of consumption of cassava peel decreased (J.O. Ifut and L. Reynolds, unpublished data). Growth rates of young male West African Dwarf goats on a *Gliricidia*-only diet was 23 g/day and was unaffected by the addition of *Panicum*. Surprisingly, however, growth rates tended to fall when *Gliricidia* and cassava tubers were offered, although digestible DM intake was higher than on the *Gliricidia*-only diet (Ademosun, Bosman et al. 1985).

A study in Sri Lanka of Bannur ewes offered combinations of *Gliricidia* and *Brachiaria miliiformis* showed little difference in lamb growth rates as the proportion of *Gliricidia* in the diet increased from 25 to 75%. However, lamb growth rate was twice as high with 25% *Gliricidia* as with the grass-only diet (Chadhokar and Kantharaja 1980).

Leucaena and *Gliricidia* in combination

The risk of *Leucaena* toxicity can be reduced by combining it with *Gliricidia*. This strategy maintains the high protein quality of the feed and decreases mimosine intake. Ademosun, Bosman et al. (1985) reported that when the *Leucaena* to *Gliricidia* ratio offered was 1:3, animals ate almost all the *Leucaena*; however, with a 1:1 mixture, animals were not selective. Similar observations have been made by ILCA at three levels of supplementation using 1:1 mixtures. Total daily browse intake ranged from 130 to 450 g DM/head, although *Leucaena* was generally consumed first. Dry matter digestibility was studied by Ademosun, Bosman et al. (1985) with mixed browse and found to be around 60% for all combinations tested (Table 5). Growth rates in young male goats over a 44-day period were highest (33 g/day) when *Leucaena* comprised 30% of the total intake; at higher levels of *Leucaena* intake (43% of total), growth rates were 26 g/day (this difference is not significant). It is possible that with higher levels of *Leucaena*, mimosine and DHP may be sufficient to affect the utilization of absorbed nutrients without apparent clinical signs of toxicity.

The effects of mixed browse on the productivity of West African sheep have been reported by Reynolds and Adeoye (1985). Supplementation with a 1:1 mixture of *Leucaena* and *Gliricidia* with a daily intake of up to 450 g DM/head raised productivity by 55% compared with sheep offered unrestricted amounts of *Panicum maximum* (Table 6). Improvements were noted in lambing interval, survivability of lambs, and growth rate to weaning. *Leucaena* was estimated to be less than 30% of total intake, which is below the level recommended by NAS (1977) to avoid toxicity. The productivity of free-roaming village sheep (Mack 1983), however, was equal to that of experimental animals receiving ad lib *Panicum* and consuming 270 g DM/day of mixed *Leucaena* and *Gliricidia*. Preliminary results from a similar trial with West African Dwarf goats indicate that daily growth rates for kids from birth to 90 days is approximately half that recorded for lambs.

The productivity of small ruminants under traditional management in southern Nigeria has been reported by Mack (1983) and Adeoye (1985) after vaccination against "peste des petits ruminants" (PPR) (Table 7). The intervention to control PPR had a beneficial effect on goat productivity in southwest Nigeria. Attempts to

Table 5. Daily dry matter intake (g/kg live weight$^{0.75}$) and digestibility (%) of diets containing varying proportions of *Leucaena* and *Gliricidia* fed to West African Dwarf goats.

Diet	Intake			Digestibility
	Leucaena	*Gliricidia*	Bark	
Leucaena	25.6	45.3	—	59.7
and *Gliricidia*	22.1	39.2	11.7	62.0
leaves + bark	28.8	28.8	9.6	62.3

Source: Ademosun, Bosman et al. (1985).

Table 6. The effects of browse supplementation with ad lib *Panicum maximum* on the productivity of West African Dwarf sheep.

	Daily browse intake (g DM/head)[a]			
	0	130	270	450
Parturition interval (days)	262±13.5	228±19.1	226±8.4	241±8.9
Litter size	1.26±0.09	1.27±0.09	1.19±0.08	1.17±0.08
Survival rate to 90 days	0.65	0.52	0.65	0.82
Birth weight (kg)	1.80±0.07	1.61±0.10	1.52±0.07	1.72±0.07
Daily live weight gain to 90 days (g)	64.4±2.98	60.3±3.51	73.4±4.98	83.8±3.69
Productivity index (kg/year)[b]	8.67	7.44	10.15	13.46

Source: Reynolds and Adeoye (1985).
[a] Browse: 50% *Leucaena* and 50% *Gliricidia*. DM, dry matter.
[b] Mass (kg) of lambs weaned at 90 days per ewe per year.

quantify the benefits of PPR control in southeast Nigeria ceased when many unprotected animals in control villages died during an outbreak of PPR and owners of the survivors withdrew their cooperation.

All components of the productivity index (parturition interval, litter size, birth weight, survival to weaning, and growth rate) were lower for animals in the southeast (e.g., Fig. 2). In addition, mortality was higher in the southeast (Fig. 3). Because browse is an important dietary component of free-roaming forest and savanna goats in southeast Nigeria (Carew 1982), dietary differences are believed to be a major factor. Confined or tethered animals do not have the same freedom of choice. The longer kidding interval may also reflect does coming into season while confined or tethered, where no buck is available until the farmer borrows one from a neighbour. Water is not generally offered to confined or tethered animals; they must rely on the water content of feedstuffs. Tethered animals are unlikely to obtain sufficient water from this source in the dry season, and lactating does will be particularly disadvantaged.

An average alley farm (0.2 ha) could provide 50% of the daily requirements for 2.6 animals; an intensive feed garden (0.01 ha) could provide 12.5% of the daily intake for 3.6 animals (see Reynolds and Atta-Krah, this volume). Farmers in

Table 7. The productivity of West African Dwarf sheep and goats on small farms in southern Nigeria.

	Southwest Nigeria			Southeast Nigeria
		Goat		
	Sheep[a]	1[a]	2[b]	Goat[c]
Parturition interval (days)	322	259	272	295
Litter size	1.23	1.49	1.65	1.30
Survival rate to 90 days	0.84	0.67	0.86	0.73
Survival rate to 365 days	0.72	0.52	0.65	0.41
Birth weight (kg)	2.12	1.57	1.62	1.23
Daily live weight gain to 90 days (g)	74	35	46	40
Productivity index (kg/year)[d]	10.28	6.64	10.71	5.67

[a] Source: Mack (1983), unimproved traditional system.
[b] Source: Adeoye (1985), with "peste des petits ruminants" control.
[c] Source: S.A.O. Adeoye (unpublished).
[d] Mass (kg) of offspring weaned at 90 days per ewe per year.

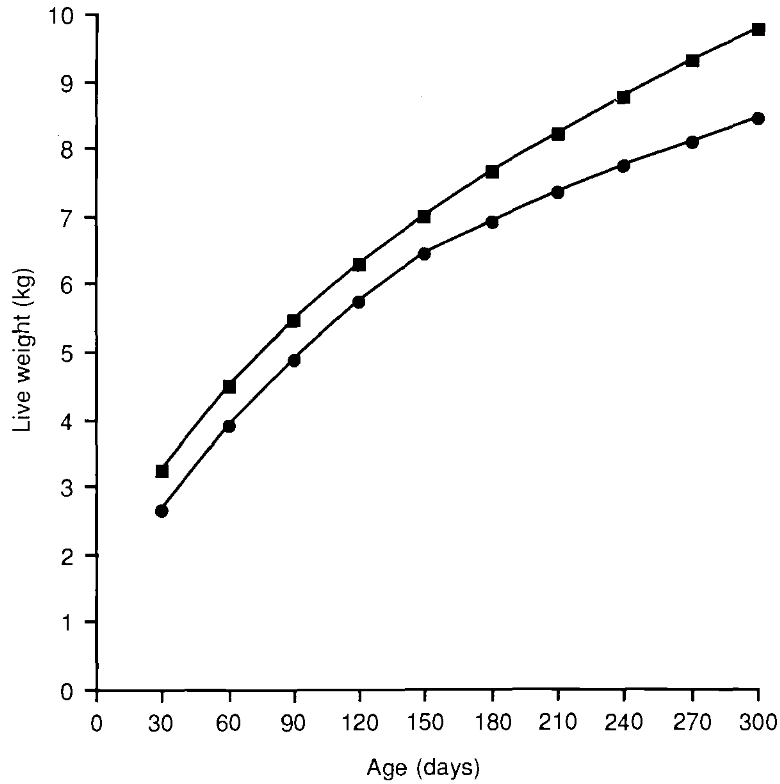

Fig. 2. Growth of free-roaming goats in southwest Nigeria (■) and tethered goats in southeast Nigeria (●) after "peste des petits ruminants" control.

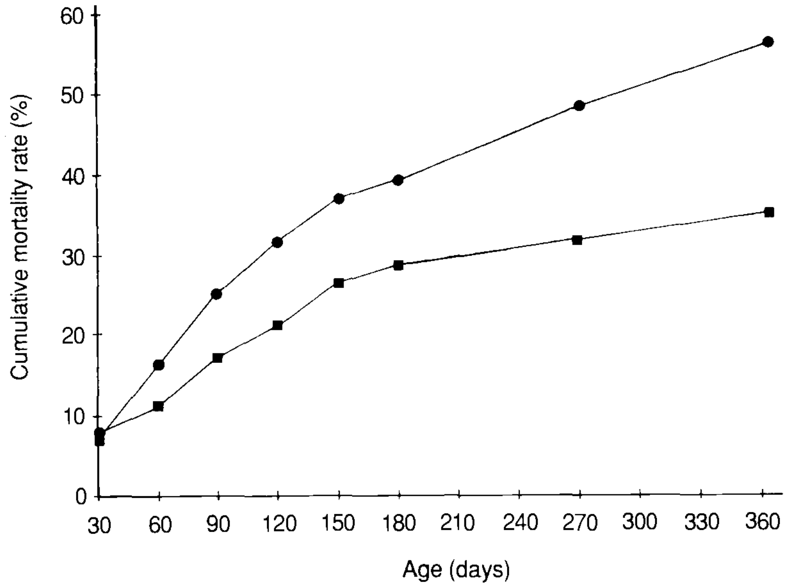

Fig. 3. Mortality of free-roaming goats in southwest Nigeria (■) and tethered goats in southeast Nigeria (●) after "peste des petits ruminants" control.

southeast Nigeria who have planted intensive feed gardens and alley farms regularly provide *Leucaena* and *Gliricidia* to their animals; however, foliage is insufficient to ensure a continuous supply. Strategic supplementation of females in the late stages of pregnancy and in lactation could be a suitable method for making the best use of a limited supply of tree foliage. This would be practicable where tethered animals could be fed individually. Extrapolation from on-station trials would suggest that the daily provision of 180 g browse DM/head, equivalent to around 30% of daily intake during the final 2 months of pregnancy and first 3 months of lactation, could raise productivity by 30%. Sumberg et al. (1985) have indicated that, with PPR control, an increase in productivity of 23% is needed to make the use of foliage for feed economically competitive with the use of prunings for mulch. In the absence of PPR control, an increase in animal performance of 30% is needed to outweigh the benefits obtained from mulch. Hard data from on-farm trials are needed to confirm the economic model.

Conclusion

The integration of crop and livestock production can benefit both components. In much of Africa, crop residues are not used for animal feeding and manure is not returned to arable fields. Planted leguminous browse trees have been shown to offer the potential for maintaining soil fertility and crop production yields, simultaneously providing animal feed. On-farm trials in southern Nigeria have shown that *Leucaena leucocephala* and *Gliricidia sepium* can be incorporated into existing farming systems in a manner acceptable to small farmers. On-station trials have quantified the benefits to crop and livestock production that can be obtained through the use of *Leucaena* and *Gliricidia* foliage. Dry matter intake and digestibility increase when mixed browse is offered as a supplement to a diet of *Panicum maximum*. The inclusion of an energy-rich feedstuff such as cassava tuber or cassava peel can raise digestibility of a *Gliricidia* diet by almost one third. Cassava peel is already commonly offered as a supplement to small ruminants in villages. The combination of *Leucaena* and *Gliricidia* browse, rich in crude protein, with high-energy cassava peel could be a particularly beneficial supplement for confined or tethered animals.

The average size of an intensive feed garden in southeast Nigeria is 0.01 ha which, if planted solely with trees, could provide sufficient browse in a cut-and-carry system to meet 12.5% of the daily DM requirements of 3.6 small ruminants. Taking the average size of alley farms in southwest Nigeria as 0.2 ha, this could provide 50% of the daily requirements of 2.6 animals. Strategic supplementation of pregnant and lactating females could be more economical use of a limited supply of browse. On-station trials have shown that supplementation could increase the survival and growth rates of young animals up to weaning age, and decrease the parturition interval for adult females. At present, the productivity of confined and tethered animals lags far behind that of free-roaming animals. The use of leguminous browse as a feed supplement could help to narrow this gap. In the dry season, feed quality and quantity are more critical for confined and tethered animals and an alternative strategy could be to concentrate on supplementation during this period. On-farm measurements are required to ascertain the relative economics of tree foliage used either as mulch or feed and to test the assumptions derived from on-station trials, on which the model was built.

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Nitrogen-fixing trees for fodder and browse in Africa

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Abstract — *Several outstanding nitrogen-fixing tree species are widely known, although basic information on their genetic potentialities is lacking. Many other species or genera deserve serious evaluation, particularly for dry matter digestibility, site (stress) adaptability, and tolerance of regular coppicing for use in alley farming. Many nitrogen-fixing trees and shrubs remain to be identified, making any review of this type only a progress report. Of the 640 known N-fixing trees and shrubs, however, about 80 are of good browse–fodder value. Data for dry matter digestibility are available for relatively few of these species and are often disappointing, although protein values for these species are often high. Finally, of these remnant species, few have been evaluated in some type of continuously coppiced, alley crop system.* Gliricidia *and* Leucaena *provide outstanding fodder species for alley farming, and their germ plasm deserves continued expansion, hybridization, and evaluation.*

Introduction

From an estimated total of 5 000 nitrogen-fixing woody species, it is possible to selectively reduce this number to 640 known fixers (Halliday 1984), to about 80 known browse–fodder plants (see Appendix), and finally to perhaps 5 really good specimens. This type of selective elimination can lead two ways:

- encourage intensive activity with the few outstanding, nitrogen-fixing tree fodder species (e.g., *Gliricidia sepium* and *Leucaena leucocephala*) and
- encourage extensive studies to identify promising new species to add to the outstanding ones.

Our research with 12 *Leucaena* species and 1 species of *Gliricidia* surely encourages the first approach, as their genetic reservoirs have hardly been tapped. For example, it becomes increasingly evident that *L. leucocephala* (the species of commerce) hybridizes with all 11 other species in the genus and several of these have commercial potential. The exciting "discovery" of species such as tagasaste (*Chamaecytisus palmensis*), however, encourages the second approach. Whichever the approach, there is most assuredly a dearth of information on shrubby fodder trees of high digestibility that are suitable for small farm cropping systems.

Nitrogen-fixing trees as fodder plants

A vast array of trees and shrubs serves as animal fodder in the tropics and subtropics, often browsed or casually lopped and fed (Skerman 1977; Le Houerou 1980). About 80 species were selected for review, and are known to serve as fodder and known or believed to fix nitrogen (Allen and Allen 1981; Halliday 1984). Nitrogen fixation characterizes most legumes (over 92% of mimosoids and papilionoids, but 34% caesalpinioids) and selected genera in nine other plant families: Betulaceae, Casuarinaceae, Coriariaceae, Cycadaceae, Elaeagnaceae, Myricaceae, Rhamnaceae, Rosaceae, and Ulmaceae.

The following restrictions were applied in developing the list of species for review:

- Any kind of fodder (foliage, pods, seeds, etc.) would be considered;
- Species for Africa were defined to include those present or of suspected potential anywhere in the region;
- All woody perennials that grow as shrubs or as trees were considered, excluding only prostrate subshrubs and woody vines; and
- All species were known or presumed to regrow readily when browsed or pollarded as a hedge.

All species could be grown from seed, but few are known to propagate vegetatively with ease.

Outstanding species

The fodder values of the reviewed species are designated using an empirical scale as follows: ***, excellent — fodder species of wide use and high value; **, good — species that are used and deserve research, but with limitations such as slow growth or low dry matter digestibility (DMD); *, fair — species that are used despite difficulties of use, quality, and management. Unmarked species are poor, with major limitations of use. Species designated as excellent or good are considered outstanding in the following discussion.

Among the acacias, only *Acacia aneura* and *A. nilotica* were rated good. The former has been minimally tested outside Australia and the latter is thorny; both are highly drought tolerant but slow growing. The following *Acacia* species were rated poor: *A. albida*, *A. estrophiolata*, *A. farnesiana*, *A. nubica*, *A. pendula*, *A. polyacantha*, *A. seyal*, and *A. victoriae*. Acacia is the largest and most ecologically diverse of the N-fixing genera (an estimated 1 200 species, about 800 in the Australasian assemblage) and fodder use in this genus has been widely documented (Jurriaanse 1950; Chippendale and Jephcott 1963; Everist 1969; Skerman 1977; Bamualin et al. 1980; Pellew 1980). Many *Acacia* species have outstanding drought tolerance and probably deserve more serious evaluation as fodder species. However, most of the listed species have low digestibility, thorniness, slow growth, or other undesirable traits.

Species of the genus *Albizia* are often toxic and high in tannins, although fodder growth can be rapid; none are rated here as good fodder. *Cajanus cajan* (*) is an unimportant fodder species, but has a fair DMD and is the subject of intensive international research as a food crop. A few tall, late varieties are strongly perennial and may be better adapted for alley farming. *Chamaecytisus palmensis* (**) is an exceptionally interesting temperate shrub with good fodder yields and quality. *Desmanthus virgatus* (**) shows aggressive growth and has good DMD; this species deserves continued research, but generally occupies the same ecological niche as *Leucaena*, which generously outyields it. More should be known of the other *Desmanthus* species. The shrubby *Desmodium* spp. (*) are fairly palatable and vigorous but of little use as fodder species.

Gliricidia sepium (**) is widely accepted by farmers who appreciate its ease of vegetative propagation. It is outyielded by many fodder legumes, but reports on its fodder quality are good. It is generally unacceptable to free-browsing animals (evidently because of malodours or toxins), but is highly acceptable when cut and carried.

Leucaena leucocephala (***) is rated highly internationally and is the subject of extensive research; it is notably limited to nonacid soils and the warm tropics. Several *Leucaena* species among the 12 or more in this genus are of interest in breeding to improve these traits, including *L. collinsii*, *L. diversifolia*, *L. lanceolata*, and *L. pulverulenta*. Psyllid insects have become a problem on *Leucaena* spp. in the Philippines and Pacific Islands, but the use of parasites and predators in controlling psyillids can be effective. Genetic tolerance is also common in *Leucaena*.

Several *Prosopis* spp. are noted as useful dryland fodders (largely for their pods) but are often thorny and slow in growth. Thornless variants occur in *P. alba* and *P. pallida*. *Sesbania grandiflora* (*) is a widely grown food and ornamental tree that makes fodder but is often short-lived and restricted in habitat. *Sesbania sesban* lends itself to alley farming but is of dubious fodder value.

Economically important N-fixing trees of Africa

Indigenous African flora includes nitrogen-fixing species of at least two families: Leguminosae and Myricaceae (Table 1). Economically important, nitrogen-fixing trees native to Africa include many leguminous species (Table 2). In the revision of Dalziel's (1937) classic text, the taxonomy of many of these species is being clarified and the synonym is listed.

Many leguminous trees do not fix nitrogen, notably genera of Caesalpinioideae (e.g., *Bauhinia*, *Caesalpinia*, *Cassia*, and *Parkinsonia*). Nodulation has not been reported for the following leguminous trees of importance in Africa: *Afzelia bella* and related *Afzelia* spp., *Anthonotha fragrans* and *A. macrophylla*, *Brachystegia* spp., *Daniellia* spp., *Detarium microcarpum* and *D. senegalense*, *Dialium guineense*, *Eruthrophleum ivorense* and *E. guineense*, *Isoberlinia doka*, *Millettia* spp., *Ostryoderris lucida*, *Parkia clappertoniana*, *Pentaclethra* spp., *Piptadeniastrum africanum*, *Tetrapleura tetraptera*, and *Virgilia divaricata*. Many of these species are economically important and clearly deserve to be assessed for nodulation capability and effective rhizobia sought.

Important N-fixing trees that have been introduced to Africa include *Acacia auriculiformis*, *Acrocarpus fraxinifolius*, *Cajanus cajan*, *Casuarina equisetifolia*,

Table 1. Genera of N-fixing trees with species native to Africa.

Family and subfamily	Genus
Leguminosae	
Caesalpinioideae	*Brachystegia, Cassia, Colvillea, Cordeauxia*[a], *Dialium, Erythrophleum, Gossweilerodendron, Intsia, Parkinsonia, Trachylobium*
Mimosoideae	*Acacia, Albizia, Dichrostachys, Entada, Mimosa, Parkia, Pentaclethra, Prosopis*
Papilionoideae	*Baphia, Cajanus*[a], *Craibia, Dalbergia, Dalbergiella, Dewevrea, Erythrina, Flemingia*[a], *Genista, Laburnum, Lonchocarpus, Millettia, Mundulea, Ormocarpum, Ormosia, Ostryoderris, Pericopsis, Pterocarpus, Sesbania, Sophora, Tephrosia*[a], *Virgilia, Xanthocercis, Xeroderris*
Myricaceae	*Myrica*

[a] Shrubby genus.

Enterolobium cyclocarpum, *Gliricidia sepium*, *Leucaena leucocephala*, *Samanea saman*, and *Tamarindus indica* (rarely nodulating, but recently confirmed to nodulate in China).

Forage quality

Forage quality and other data for N-fixing fodder trees and shrubs are available as an expanded data base from the Nitrogen Fixing Tree Association, Wiamanalo, HI, USA. A related data base with all fodder trees is being developed at the International Council for Research in Agroforestry (ICRAF) in Nairobi, Kenya (Robinson 1985); the 22 species rated "fair" to "excellent" represent about 25% of the 80 reviewed here and account for less than 10% of those indicated as fodder trees in the literature reviewed. It is clear that forage quality has much to do with this attrition. Many legume shrubs and trees are simply unpalatable to animals.

Dry matter digestibilities are the most important values for tropical legumes. They are as yet available for only a few species and are clearly to be desired for all. Dry matter digestibility values are now obtained most readily using in vitro enzymatic digestion by bacterial cellulases (McLeod and Minson 1978). They are also derived from fistulated animals with the nylon bag technique. DMD values averaged 60% for leaves of 17 fodder legume species (Minson and Wilson 1980) and correlated well with fibre and lignin values (Bamualin et al. 1980). Values cited are presumed to represent "bite sample," unless otherwise noted, and are drawn largely from the studies of Russel (1947), McLeod (1973), Bamualin et al. (1980), Singh (1982), and Mahyuddin (1983). The values range widely from the high 60s for species like *Gliricidia* and *Leucaena* down to the 30s for fibrous, often phyllodinous species. Animal intake is related directly to DMD and, within a species, to DMD of the tissues browsed (Minson 1983).

Table 2. Tree species known to fix nitrogen, native to Africa, and of economic importance.

Species	Uses
Acacia albida Del.	Browse, firewood, tannin
Acacia nilotica (L.) Willd. ex Del.	Browse, firewood, charcoal, tannin, gum
Acacia senegal (L.) Willd.	Browse, firewood, charcoal
Acacia tortilis (Forsk.) Hayne	Fodder, firewood
Albizia gummifera (Gmel.) C.A. Smith	Browse, charcoal
Albizia lebbek (L.) Benth.	Fodder, firewood, furniture
Baphia nitida Lodd.	Browse, firewood, living fences, dye
Brachystegia spiciformis Benth.	Firewood
Cordeauxia edulis Hemsl.	Browse, nuts, dye
Dalbergia melanoxylon Guill. & Perr.	Timber
Entada abyssinica Steud. ex A. Rich	Browse, fruit
Entada africana Guill. & Perr.	Firewood
Erythrina abyssinica Lam.	Browse, green manure, fruit
Erythrophleum africanum (Welw. ex Benth.) Harms	Charcoal, timber
Erythrophleum suaveolens (Guill. & Perr.) Brenan	Charcoal, timber
Flemingia macrophylla (Willd.) Merrill (=*F. congesta* Roxb.)	Browse
Gossweilerodendron balsamiferum (Verms) Harms	Timber
Lonchocarpus sericeus H.B.K.	Timber
Parkia filicoidea Welw. (syn. *P. africana* (R.Br.))	Browse, firewood, edible seeds, dye
Prosopis africana (Guill. & Perr.) Taub.	Firewood, tannin
Pterocarpus santalinoides L.	Timber, leafy vegetable
Pterocarpus soyauxii Taub.	Timber, leafy vegetable
Sesbania sesban (L.) Merr.	Fodder, green manure
Tephrosia candida (Roxb.) DC.	Green manure
Trachylobium verrucosum (Gaertn.) Oliv.	Resin
Virgilia capensis (L.) Poir	Firewood, gum
Xeroderris stuhlmannii (Taub.) Mend. & Sousa	Browse, timber

High tannins, as in *Calliandra*, clearly act as a feeding deterrent. Several toxic substances have been identified in the species reviewed (e.g., robitin in *Robinia* and cyanogenic glycosides and fluoroacetic acid in *Acacia* spp.). Strong odours of crushed leaves (e.g., *Gliricidia* and *Pongamia*) often are associated with low animal intake. Other toxins are known for *Cytisus*, *Erythrina*, and *Sophora* spp.

Feeding deterrents occur in many N-fixing species, a natural result of the coevolution of these plants and herbivorous animals. Thorns are the most obvious, but N-containing toxins the cyanogenic compounds occur among legumes (Mahyuddin 1983).

Species mixtures and mixed feeds

Managers of temperate herbaceous pastures think automatically of mixed grass–legume stands. Some examples of successful agroforestry systems in the tropics include *Leucaena* hedgerows in grass pastures, scattered timber or fuelwood trees in grass pastures, and borders or fencerows of legumes such as *Gliricidia* around animal-grazing areas.

A remarkable number of highly palatable fodder trees do not fix nitrogen (Le Houerou 1980; Singh 1982); this is most notable in the tropical highlands. Nitrogen-fixing woody species become progressively more rare as one goes away from the equator; contrarily, actinorhizal plants (e.g., *Alnus*, *Ceanothus*, *Elaeagnus*, *Parasponia*) become more common. Highly productive fodder trees and shrubs that do not fix nitrogen include the following (L, legume): *Artemisia*, *Artocarpus*, *Atriplex*, *Azadirachta*, *Bauhinia* (L), *Cassia* (L), *Ceratonia* (L), *Cercidium* (L), *Ficus*, *Gleditschia* (L), *Haloxylon*, *Morus*, *Quercus*, and *Parkinsonia* (L) (Le Houerou 1978; Halliday 1984).

Species mixtures become economically viable for temperate pastures only after fine-tuning species, variety, fertility, and animal-management patterns. The mixtures of woody species, grasses, and crops in alley farming systems deserve similar, long-range consideration for most economic browse or cut-and-carry systems in the tropics.

It is clear that the loss of forests in the tropics, occurring at a rate of 10–20 $\times 10^6$ ha/year, will make the wild fodder tree a thing of the past for many countries (Brewbaker et al. 1982). Tropical forests are expected to cover only 750 $\times 10^6$ ha by the year 2000, a loss of 75% in this century alone. Most of this remnant will be in the Americas and Indonesia. Natural grazing lands, however, cover over 3 $\times 10^9$ ha. The addition of legume shrubs and trees to this land could have a major impact on the intake and nutritional value of fodder. Multipurpose trees that can serve both as fodder and fuelwood will be increasingly valued in the tropics, and fodder should be an economically important coproduct of fuelwood and timber harvest (Brewbaker et al. 1984; Burley and Von Carlowitz 1984).

Excellent reviews of fodder shrubs and trees include those on legumes by Skerman (1977) and NAS (1979) and on Africa by Le Houerou (1978, cited in Le Houerou 1980). Regional reviews include those on Africa (Jurriaanse 1950; Dougall and Bogdan 1958; Lamprey et al. 1980; Le Houerou 1980), Australia (Chippendale and Jephcott 1963; Everist 1969), Nepal (Panday 1982), and India (Sharma 1977; Singh 1982).

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Appendix: Tropical fodder trees and shrubs that fix nitrogen

The following format is used to list and describe the shrub and tree species in this Appendix.

Genus and *species*; "common names" (family: subfamily of first species in genus)

1. Centre of origin; distribution; uses.
2. Description; botany; ecology.
3. Forage value (***, excellent; **, good; *, fair to poor); use as forage; digestibility; problems.

Acacia albida Del; "Winterthorn," "Kad" (Leguminosae: Mimosoideae)

1. Africa; widespread, now to India, Israel; fodder, ornamental, shade, green manure.
2. Tree to 20 m = *Acacia leucophloea*; leafless in rainy season, bipinnate, thorny; drought tolerant to 300 mm, frost sensitive.
3. *; pods eaten, also foliage (dry season); fast growth if watered (10 m in 7 years).

Acacia aneura F. Muell. ex Benth; "Mulga"

1. Australia; widespread; hard wood, fuelwood, ornamental, variably browsed by stock.
2. Shrub or tree to 12 m; phyllodes; slow growth, high drought tolerance (to 200 mm), frost tolerant, frost sensitive.
3. **; some varieties good stock fodder, the "most important fodder tree in Australia" (Everist 1969), widely browsed; low foliage DMD (39%), little success in Africa.

Acacia angustissima Miller

1. Central America.
2. Shrub to 5 m; not thorny; rapid growth.
3. Fodder in Indonesia.

Acacia bidwillii Benth.; "Corkwood Wattle"

1. Australia.
2. Tree to 7 m, related to *A. calcigera*; bipinnate; mesic.
3. Good fodder.

Acacia coriacea (DC.) "Wirewood," "Desert Oak," "Dogwood"

1. North Australia, 1.5 m ha; introduced in Africa.
2. Shrub to 7 m; phyllodes; slow growth, high tolerance of drought and fire.
3. Leaves and pods eaten but of poor palatability, best when dry; low leaf yield.

Acacia currasavica

1. America; forage.
2. Shrub to 5 m; thornless, bipinnate; cold tolerant.
3. Leaf DMD = 64% (stems 28%).

Acacia estrophiolata F. Muell.; "Ironwood"

1. Australia only.
2. Tree to 15 m; phyllodes; slow growth, long life, drought tolerant.
3. *; foliage eaten avidly; grows too tall.

Acacia excelsa Benth.; "Ironwood," "Ironwood Wattle"

1. Northwest Australia; fuelwood, fodder.
2. Tree to 10 m; fair drought tolerance.
3. Eaten freely by sheep, but can cause impaction.

Acacia farnesiana (L.) Willd.; "Cassie," "Huisache" (Mexico), "Sweet Acacia," "Mimosa Bush," "Klu" (Hawaii)

1. Americas, now worldwide; ornamental, cultivated for perfume, tannin, dyes, gums.

2. Shrub 2–7 m; bipinnate, forms thickets, stipular spines (< 1 cm); frost tolerant, rapid growth, weedy, tolerant of heavy clay.
3. *; pods browsed when young; foliage DMD = 54%, contains cyanogenic glycosides.

Acacia holosericea A. Cunn ex G. Don

1. North Australia; grows well in Africa; fuelwood, ornamental, hedges.
2. Shrub to 5 m; phyllodes; widely adaptable, tolerant of salinity, not tolerant to prolonged drought.
3. High fodder production, but not fed fresh, only as dried phyllodes.

Acacia homalophylla A. Cunn. ex Benth.; "Yarran"

1. Northwest Australia; fodder.
2. Tree to 8 m; phyllodes.
3. Leaves eaten readily, similar in value to *Acacia aneura*.

Acacia litakunensis Burch; "Umbrella thorn"

1. Southern Africa; fodder.
2. Tree to 10 m; thorny, bipinnate; forms thickets.
3. Pods are a favoured fodder.

Acacia neriifolia A. Cunn. ex Benth.; "Silver Wattle"

1. Australia; windbreaks, emergency stock fodder.
2. Shrub to 8 m; phyllodes; drought and frost tolerant.
3. Foliage browsed only in times of stress.

Acacia nilotica (L.) Willd. ex Del, "Babul" (India), "Munga" (Africa), "Prickly acacia" (Australia)

1. India and Africa; now widespread; firewood, charcoal, tannin and gum source, fodder.
2. Tree 6–12 m; very thorny, bipinnate; tropics, midlands, frost susceptible, drought tolerant, deciduous.
3. **; good leaf and pod fodder yields and quality; pods sweet, readily eaten, but can cause bloat; many insect pests.

Acacia nubica Benth.; "Last" (Sudan)

1. Northeast Africa; browse shrub.
2. Shrub to 5 m; thorny bipinnate.
3. *; important browse shrub in Africa.

Acacia pendula A. Cunn. ex G. Don; "Myall"

1. Australia; introduced to Israel; fodder, shade tree, timber, fuelwood.
2. Tree to 8 m; stately, phyllodes; subtropical, drought tolerant.
3. *; drought-stock fodder; foliage DMD = 47%.

Acacia polyacantha Willd.; "Khair," "Catechu Tree"

1. Africa, India; fodder, charcoal, black gum, dye.
2. Tree to 25 m, = *A. catechu*; recurved spines, bipinnate, weedy; midlands to 1 000 m, takes mild frost, low drought tolerance, coppices well, long life.
3. *; fair growth rate; good fodder DMD (61%); many insect and diseases, low tannin (1.5%).

Acacia saligna (Lindl.) H. Wendl.; "Coolan," "willow"

1. West Australia (now widespread); common in Southern and North Africa; ornamental, fodder, fuel, erosion control, dune stabilization.
2. Tree to 8 m, = *S. cyanophylla*; phyllodes; rapid growth, tolerant of drought, fire, salt, and wind.
3. Little browsed; may be toxic to cattle, high tannin in leaves and saponins in pods.

Acacia senegal (L.) Willd.; "Gum-arabic Tree," "Hashab"

1. Africa to India; firewood, charcoal, gum arabic, fodder.

2. Tree to 10 m, but often shrubby; deciduous, thorny bipinnate; dry tropics to 200 mm rainfall.
3. Not important as feed, but pods and foliage used by goats and camels.

Acacia seyal Del.; "Thirsty Thorn," "Dushe" (Nigeria)
1. North Africa; wood, gums, and tannins, important feed (pods, leaves, bark).
2. Slender tree to 12 m; bipinnate, long thorns; semi-arid tropics.
3. *; bark is a valued feed, up to 10% protein; leaves and pods also fed in Africa.

Acacia sieberiana DC.
1. West Africa; gum, fodder, honey, furniture wood.
2. Tree to 10 m; drought tolerant but found along streams.
3. Valued as drought-season fodder.

Acacia tortilis (Forsk) Hayne
1. Africa; introduced to tropical Asia; firewood, fodder.
2. Flat-topped tree to 15 m, but often shrubby; thorny, bipinnate; dry tropics, to 100 mm, alkali tolerant, not frost tolerant, to 1 200 m in Kenya.
3. Leaves browsed by goats, pods are main feed ("tortilis" = curled pod).

Acacia trachycarpa E. Pritzel
1. Australia.
2. Small tree to 5 m; phyllodes; long life, fair drought resistance.
3. Readily browsed, but slow growing.

Acacia victoriae Benth.; "Gundabluey," "Acacia Bush," "Elegant Wattle"
1. Australia (widespread); fodder, ornamental, windbreak.
2. Shrub to 5 m; straggly, often thorny; short life, often in thickets, sandy soil, saline and drought tolerant (to 350 mm).
3. *; pods browsed, of moderate palatability; leaves retained year-round but low in yield.

Acacia villosa Willd.
1. Caribbean, common in Indonesia.
2. Shrub to 3 m; highly branched, bipinnate, compact leaves; low-elevation tropics.
3. Forage of low value, high tannins (6%).

Acacia xanthophloea Benth.
1. Africa, India; ornamental, fodder.
2. Tree to 20 m; handsome, yellow green, spiny, bipinnate; frost-free tropics.
3. High yields of lopped fodder.

Other *Acacia* spp. that are recorded as fodder trees (Everist 1969; Skerman 1977), but are of doubtful value are *A. argyrodendron*, *A. anqustissima*, *A. brevispica*, *A. cyperophylla*, *A. deanei*, *A. doratoxylon*, *A. gerrardii*, *A. harpophylla*, *A. kempeana*, *A. macrothyrsa*, *A. manqium*, *A. mellifera*, *A. nigrescens*, *A. oswaldii*, *A. salicina*, *A. shirleyi*, *A. sparsiflora*, *A. stenophylla*, *A. sutherlandii*, *A. tetragonophylla*, and *A. tumida*.

Aeschynomene americana L.; "Thornless Mimosa" (Leguminosae: Mimosoideae)
1. Tropical America; now widespread; fodder, hay.
2. Subshrub to 2 m; lowland mesic tropics, tolerant of waterlogged soils.
3. Fair palatability.

Aeschynomene elaphroxylon (Guill. and Perr.) Taub.; "Ambatch," "Pith Tree," "Balsawood Tree"
1. Tropical Africa; now widespread; light, corky wood, fodder.
2. Shrub or small tree to 9 m, = *Herminiera elaphroxylon*; mesic and swampy tropics to 2 000 m.
3. Leaves palatable but sparse; thorny, with sticky hairs on branches.

Albizia chinensis (Osb.) Merr. (Leguminosae: Mimosoideae)

1. India; in North India to 1 300 m; timber, fodder, shade tree.
2. Tree to 15 m; deciduous; rapid growth, mesic and dry subtropics.
3. Low DMD (38%); toxic symptoms from prolonged feeding, notably on young leaves; is fed in mixtures.

Albizia falcataria (L.) Fosberg

1. Indonesia, New Guinea; widespread in humid tropics; timber (low specific gravity, 0.33), pulpwood, soil improvement.
2. Tree to 40 m; humid tropics to 1 000 mm, midlands.
3. = *Periserianthes falcataria*; low DMD (39.2%), intake low, tannins not high (2%).

Albizia lebbeck (L.) Benth.; "Siris," "Woman's Tongue"

1. Asia, Africa; worldwide now; ornamental, fuelwood, fodder, furniture wood.
2. Tree to 25 m; wide adaptability, dry humid tropics, to 1 500 m, to 600 mm rainfall, growth to 8 m in 8 years.
3. Supplementary fodder; DMD 45–55% (to 73%; Singh 1982).

Albizia odoratissima Benth.

1. Nepal, India; ornamental, fodder.
2. Tree to 25 m; humid subtropics, to 1 500 m.
3. Highly lopped for fodder in Nepal, fair quality.

Albizia procera (Roxb.) Benth.; "Safed Siris"

1. India, Southeast Asia; now widespread; lumber, fuel, furniture, shade tree.
2. Tree to 20 m; humid subtropics, to 1 800 m, not frost tolerant.
3. Browse for buffalo, deer.

Albizia stipulata (DC.) Boiv.; "Rato Siris"

1. Nepal; fodder.
2. Tree, resembles *A. moluccana*; highlands to 2 000 m.
3. Lopped fodder.

Other *Albizia* spp. recorded as fodders include *A. adianthifolia, A. amara, A. basaltica, A. harveyi*, and *A. richardiana*.

Baphia nitida Lodd.; "Camwood" (Leguminosae: Papilionoideae)

1. West Africa; wood for dyes, fodder, construction, medicinal, ornamental, fencerows.
2. Shrub to 3 m or tree to 10 m; humid tropical forests.
3. High palatability as browse.

Cajanus cajan (L.) Millsp.; "Pigeon Pea," "Dhal," "Catjang" (Asia)(Leguminosae: Papilionoideae)

1. Africa (cultivated around 2000 BC); India, worldwide; food, medicinal, green manure, fodder, windbreak, honey.
2. Variably perennial shrub to 4 m; annual types for food; dry tropics, low to midland, not frost or fire tolerant.
3. *; rare use as fodder, browse or hay (including pods); leaf DMD = 53%, small stem DMD = 42%; not persistent under grazing or coppicing.

Calliandra calothyrsus Meissn.; "kaliandra" (Leguminosae: Mimosoideae)

1. Central and South America; fuelwood, green manure, fodder, ornamental.
2. Shrub to 8 m; moist tropics, cold tolerant, rapid growth, acid tolerant, poor on alkaline soils.
3. Low fodder value but fast growth; low DMD (41%), high tannins (7%).

Calliandra eriophylia Benth.; "False Mesquite"

1. Mexico to USA; browse, fuelwood.
2. Shrub to 3 m, dense; thornless.
3. Browse of unknown value to livestock and deer.

Casuarina L. spp. (Casuarinaceae)

1. Australia and Asia; widespread; firewood, charcoal, ornamental.
2. Trees; tropical, saline tolerant.
3. Browsed and sometimes fed but of poor quality; low intake and DMD (< 40%), high fibre, low protein.

Cathormion umbellatum (Leguminosae: Mimosoideae)

1. North Australia; browse.
2. Shrub to 7 m, resembles *Samanea* spp.
3. Low leaf DMD (35%).

Ceanothus L. spp. (Rhamnaceae)

1. Americas; browse.
2. Shrubs to 4 m; drought hardy, diverse.
3. *C. cuneatus* and *C. divaricatus* noted as good fodder plants.

Chamaecytisus palmensis (Christ) Bisby et Nicholls; "Tagasaste," "Tree Lucerne" (Leguminosae: Papilionoideae)

1. Canary Islands, to New Zealand; hedges, fodder, bee pasture.
2. Shrub to 6 m; temperate, frost tolerant to −10°C, drought tolerant, not tolerant of acid soils.
3. **; good browse or fodder, leaf DMD = 70%, browse DMD = 53%.

Codariocalyx gyrans (L.) Hassk.; "Telegraph Plant" (Leguminosae: Papilionoideae)

1. Indo-Malaysia, Philippines; green manure.
2. Shrubs and sub-shrubs; related to *Desmodium*.
3. Palatable to stock.

Codariocalyx gyroides (Roxb.) Hassk.

1. Indo-Malaysia and Philippines; green manure, coffee shade.
2. Vigorous tropical shrub to 2.5 m, = *Desmodium gyroides* DC; wet tropics, tolerant of poor drainage.
3. Low palatability to stock.

Cytisus scoparius (L.) Link.; "Scotch Broom" (Leguminosae: Papilionoideae)

1. Mediterranean region; ornamental, hedge, fencerows, browse.
2. Shrub to 4 m; temperate.
3. Browsed by sheep in New Zealand but considered poor; weedy; toxic alkaloids common in this genus.

Dalbergia sissoo Roxb.; "Sissoo," "Indian teakwood," "Tali" (Leguminosae: Papilionoideae)

1. India; timber, fuelwood, shade tree, fodder.
2. Tree to 30 m; mesic tropics and subtropics to 1 200 m and 800 mm rainfall.
3. Browsed (monkeys, deer), may be lopped for fodder; low silage DMD (20%); poor feed in dry season, fresh leaves can cause digestive disorders.

Desmanthus virgatus (L.) Willd.; "Donkey Bean" (Leguminosae: Mimosoideae)

1. South and Central America; now worldwide; browse fodder.
2. Subshrub to 3 m; coppices and reseeds well; short-lived perennial, aggressive, unarmed; mesic tropics but drought tolerant; not acid tolerant.
3. **; leaf DMD good (53%); generally similar to but outyielded by *Leucaena* spp.

Desmodium discolor Vog.; "Horse Marmalade" (South Africa) (Leguminosae: Papilionoideae)

1. South America; now widely distributed; fodder.
2. Subshrub to 3 m; woody when mature; subtropical, frost hardy.
3. *; highly palatable.

Desmodium distortum (Aubl.) Macbride

1. Venezuela; now in Africa; fodder.

2. Subshrub to 2 m; woody at base; moist tropics.
3. *; good palatability.

Dichrostachys cinerea (L.) Wight and Arn.; "Kakada" (Sudan) (Leguminosae: Mimosoideae)

1. Africa; now widespread; browse (especially pods).
2. Shrub to 5 m; thorny; mesic tropics, not tolerant of frost; weedy, forming thickets.
3. A common browse plant in Africa.

Erythrina L. spp.; "Coral tree," "Phaledo" (Nepal) (Leguminosae: Papilionoideae)

1. Americas, Africa, Asia; ornamentals, fencerows, windbreaks, shade trees.
2. Trees to 20 m; often thorny; mesic to cool tropics.
3. Reports of fodder use include *E. arborescens*, *E. bertoeroana*, *E. hookeriana*, *E. stricta*, *E. suberosa*, and *E. variegata*, none have reputation as good fodders; the genus is noted as a source of alkaloids and poisons.

Flemingia macrophylla (Willd.) Merrill; (Leguminosae)

1. Southeast Asia; dyes, fodder, green manure.
2. Shrub to 2 m, = *F. congesta* Roxb., *F. latipolia* Benth.; mesic to wet tropics, moderately shade tolerant.
3. Low DMD (40%).

Gliricidia sepium (Jacq.) Walp.; "Madre de cacao," "Quickstick" (Leguminosae: Papilionoideae)

1. Central America/Mexico; now worldwide; firewood, timber, shade, ornamental, fodder.
2. Tree to 15 m; easily propagated by cuttings; rapid growth, dry to mesic tropics to 1 000 m.
3. **; foliage variously appraised around the world, often unused, occasionally valued highly; DMD high (55% browse samples, 68% leaves); low tannins (<1%), high leaf lignin (5.5%), reportedly toxic to horses, carries toxins in bark, seeds, and roots.

Hardwickia binata Roxb.;"Anjan" (Leguminosae: Caesalpinioidea)

1. India; valued heavy wood, bark for fibre, soil stabilization, fodder.
2. Trees to 35 m; deciduous, deep taproot; slow growth, dry tropics (300 mm), needs drainage.
3. Fodder good; DMD low (47%), protein low.

Leucaena leucocephala (Lam.) de Wit; "Leucaena," "Ipil-ipil," "Lamtoro" (Leguminosae: Mimosoideae)

1. Central America, Mexico; worldwide; fodder, fuelwood, shade, pulpwood, postwood, lumber, food.
2. Tree to 20 m, widely studied and planted; dry to mesic tropics, fast growth, not acid tolerant, growth slow in highlands.
3. ***; high DMD (55–72%), good protein; restricted feed use to nonruminants because of mimosine and DHP.

Leucaena Benth. spp.

1. North America; uncommon yet international; food, fodder, fuelwood.
2. Shrubs and trees to 20 m; dry to mesic, lowland to highland.
3. *; browse fodder common on *L. lanceolata*; breeders using *L. pulverulenta*, *L. collinsii*, *L. diversifolia*, and others to improve cold tolerance, acid tolerance, and yield of *L. leucocephala*.

Medicago arborea L.; "Tree Medic," "Cytisus Shrub" (Leguminosae: Papilionoideae)

1. Greece; now common in Mediterranean; described around 100 AD as valuable goat fodder.
2. Small shrub to 4 m; greyish, silky hairs; subtemperate, not hardy against severe frost, drought tolerant.
3. *; goat browse, not widely used.

Millettia thonningii (Schum. & Thonn.) Bak. (Leguminosae: Papilionoideae)

1. West Africa; fodder.
2. Tree to 10 m, = *Robinia thonningii*; deciduous; mesic tropics.
3. Fair palatability.

Mimosa pigra L. (Leguminosae: Mimosoideae)

1. America; now worldwide; noxious weed, occasional fodder, medicinal.
2. Subshrub to 4 m; thorny; aggressive, widely adaptable, mesic tropics, weedy, makes thickets.
3. *; makes good leaf meal; DMD low (47%); tannins high (8%).

Mimosa caesalpiniifolia, *M. paupera* Benth, *M. somnians* H&B, and *M. uliginosa* Chod. & Hassl. are also described as browse plants; the latter two are spiny.

Ougeinia oojeinensis (Roxb.) Hochr. (Leguminosae: Papilionoideae)

1. North India; wood for implements, fodder.
2. Tree to 14 m; slow growth (2 m in 6 years), to 1 200 m in North India, frost and drought tolerant.
3. Lopped fodder considered fair.

Pithecellobium dulce (Roxb.) Benth.; "Kamachili" (Philippines), "Dutch tamarind" (Leguminosae: Papilionoideae)

1. America; internationally spread; fuelwood, ornamental, fodder (pods).
2. Tree to 20 m; thorny; very wide adaptability from dry to humid tropics and subtemperate regions.
3: Pods and leaves browsed; seeds relished by monkeys and birds.

Pongamia pinnata L. Pierre; "Karang," "Derris" (Leguminosae: Papilionoideae)

1. India to China, Australia, and Malaysia; oilseeds, shade tree, medicinal, firewood, fodder, craft wood, bark for fibre.
2. Small tree to 8 m, = *Derris indica*; mesic tropics (to 600 mm), salt tolerant.
3. Lopped leaves fed, but young leaves unpalatable and not browsed; DMD = 50%; seed cakes after oil removal can be used as poultry feed.

Prosopis alba Griseb. and *P. chilensis* (Mol.) Stuntz (Leguminosae: Mimosoideae)

1. Southern South America; firewood, timber, fodder (pods), shade.
2. Trees to 15 m; thorny; hot dry tropics, to 100 mm, also to highlands (3 000 m in Argentina).
3. *; pods are staple cattle food, little use of foliage.

Prosopis cineraria (L.) Druce; "Khejri"

1. India; used before 1000 BC; firewood, charcoal, fodder, green manure, post wood.
2. Tree to 9 m; thorny; hot dry tropics to 100 mm, normally 500–800 mm, light demanding.
3. *; highly valued in desert areas; DMD very low (40%); tannins very high (> 10%), seedlings heavily browsed.

Prosopis pallida H.& B. ex Willd. and *P. juliflora* (Swartz) DC; "Algaroba," "Ironwood," "Keawe" (Hawaii)

1. Central and South America; now widespread; fuelwood, charcoal, fodder (pods), honey, wood.
2. Trees to 15 m; thorny (segreg.); hot dry tropics (to 200 mm), saline tolerant.
3. *; pods important fodder source, 25% sugar, 17% protein; foliage little used.

Prosopis spicigera L.

1. West India; fodder.
2. Tree to 6 m; variably thorny; subtropical.
3. Good lopped fodder, good palatability.

Other *Prosopis* spp. providing animal feed, normally pods, include *P. glandulosa* Torr. (weedy) and *P. tamarugo* F. Phil.

Pterocarpus erinaceus Poir.; "African rosewood," "Apepe" (Leguminosae: Mimosoideae)
1. West Africa; wood for tools and posts, fodder, dyes and tannin, afforestation.
2. Tree to 15 m; mesic tropics, good on shallow soils.
3. *; foliage considered good fodder; planted as stock feed.

Pterocarpus marsupium Roxb.
1. India; fodder, fuelwood, timber.
2. Tree to 30 m; coppices and pollards well; mesic tropics, some frost tolerance.
3. *; widely lopped for fodder in India, quality fair.

Robinia pseudoacacia L.; "Black Locust" (Leguminosae: Papilionoideae)
1. North America; now widespread in highland tropics; fuelwood, ornamental, honey, reforestation, land stabilization.
2. Tree to 20 m; forms thickets; fast growth, highland tropics (to 3 000 m), one of the few temperate N-fixing legume trees.
3. *; fodder variously appraised, possibly genetically variable; low DMD (27%); toxicity of young shoots, bark, leaves, and seed reported (cattle, horses, man), alkaloids robitin and robin, also tannins (to 3%).

Samanea saman (Jacq.) Merrill; "Raintree," "Cow Tamarind" (Leguminosae: Mimosoideae)
1. Central and South America; now pantropical; ornamental, timber, craft wood, fuelwood, feed (pods).
2. Tree to 40 m, spreading; mesic to wet tropics, fast growth, widely adapted.
3. Pods can be fed to animals or used as food.

Sesbania bispinosa (Jacq.) W.F. Wight; "Daincha" (Leguminosae: Papilionoideae)
1. India, now widespread especially in Africa and North India; fodder, green manure, possible pulpwood.
2. Annual shrub to 6 m; thorny, weedy; wet or saline tropics.
3. Young leaves used as cattle fodder.

Sesbania grandiflora (L.) Poir.; "West Indian Pea Tree," "Katurai" (Philippines), "Turi" (Indonesia), "Gallito" (Caribbean)
1. Indonesia?; worldwide; food (flowers, pods, leaves), fodder, pulpwood, ornamental.
2. Tree to 10 m, = *Sesbania formosa* F. Muell.; slow foliage regeneration; short life, fast growth, mesic tropics (1 000 mm), tolerant of waterlogging.
3. *; fodder of good quality.

Sesbania sesban (L.) Merrill; "Sesban"
1. Tropical Africa (widespread), Asia; green manure, fodder, fibre.
2. Shrub to 5 m, = *Sesbania aegyptiaca* (Poir) Pers.; fast growth, moist tropics, saline and flooding tolerant.
3. Variously appraised as fodder, not widely used.

Other *Sesbania* spp. in use or under evaluation are subshrubs or shrubs and include *S. cannabina* and *S. speciosa*.

Sophora chrysophlla (Salisb.) Seem.; "Mamani" (Leguminosae: Papilionoideae)
1. Pacific Islands; Hawaii, New Zealand; fodder.
2. Small tree to 8 m; highland tropics.
3. Browsed by ruminant animals; other *Sophora* spp. carry serious toxins, notably *S. secundiflora*, which can kill animals.

Some outstanding fodder legume shrubs or trees that do not nodulate include *Bauhinia purpurea* L., *Bauhinia racemosa* Lam., *Bauhinia variegata* L., *Butea frondosa* Roxb., *Butea monosperma*, *Ceratonia siliqua* L., and *Gleditsia triacanthos* L.

Trees in forage systems

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Abstract — Native trees in dense stands can be serious competitors to herbaceous pastures. With appropriate densities and management, however, trees can exploit an expanded biotic environment in forage systems and high economic gains can be achieved. This paper outlines the attributes of useful trees in forage systems and discusses the retention of valuable native trees on grazing lands. Selection of trees of immediate use in forage systems must rely on past experiences in the target region and similar environments throughout the tropics and subtropics. Fast-growing, multiple-use, nitrogen-fixing trees are considered most important in forage systems. Leucaena leucocephala, Gliricidia sepium, *and* Sesbania grandiflora *are quick-growing leguminous trees already used throughout the humid tropics in cropping and forage systems. Selected forage types of* Cajanus cajan *can be undersown with crops. These trees can be put into farm use quickly, especially in alley cropping and alley grazing.* Leucaena *in alley grazing systems in Australia is discussed. The diversity of agroecological conditions in the tropics can impose severe constraints on crop, forage, and animal production. Research will identify better adapted nitrogen-fixing trees to suit this wide environmental range.*

Introduction

Trees and shrubs in tropical forests and savannas have provided people with shade, shelter, fuel, food, and fodder for their animals. Population and economic pressures have led to more intensive land use. This, in turn, has resulted in native trees being harvested or cleared for their economic products (e.g., building timber and fuel), the establishment of economic tree and annual crops, and the intensification of herbage forage production. In many countries, food production has not kept pace with human population growth, with drastic consequences to the stability of the environment. Special farming and forage systems are needed to increase livestock production within the ecological and socioeconomic constraints of each locality.

The development of farming systems involving both trees and crops (agroforestry) offered a means of optimizing land use. More importantly, the management practices involved in agroforestry were compatible with the cultural practices of the local population. In contrast to the shifting cultivation practices in the wet tropics, appropriate tree–multicrop systems offer a means of increasing production under a stable and rewarding environment for the farmers concerned (Watson 1983).

This paper addresses the value of trees in forage systems, the retention of useful native trees on grazing lands, and the selection of exotic trees. Alley cropping and alley grazing using *Leucaena* and other nitrogen-fixing trees are the main focal points.

Value of trees in forage systems

Trees expand the biotic environment by occupying a greater volume of the aerial and edaphic space and thereby offer protection to water catchment areas and regeneration of degraded farmlands. Trees also give shade and protection against the vagaries of the climate and, thus, create a more equitable microclimate near the ground for the benefit of food and forage crops, livestock, and humans. The canopy cover and ground mulch dissipate the energy of raindrops, increase water infiltration, and reduce moisture loss. The deep root systems tap a moisture source even in times of drought and recycle plant nutrients from depths inaccessible to crops and pastures. Nitrogen-fixing trees with highly nutritious foliage have several benefits. They add valuable nitrogen to the system as well as provide higher quality forage.

Competition for soil resources between trees and herbaceous crops and forages are minimal once the trees are well established because of the different environmental strata they occupy. There are tree species available that successfully exploit adverse environments (i.e., acid soils, saline conditions, waterlogged situations, long dry seasons, heavy clays, and deep sands) and provide economic products directly or indirectly. The economic value of the trees alone can be considerable because they may supply a variety of products such as fruit, vegetables, poles, firewood, building materials, salable timber, gum, high-value forage, and mulch. Because trees play a dominant role in plant communities, they can be integrated easily into cropping and grazing systems. Fodder trees also have the advantage of remaining productive during the dry season, when herbaceous forages dry out and decline in quality.

Native trees in forage systems

Native trees and native pastures

Pastoralists and scientists have observed useful browse plants and fodder trees in native grasslands (Everist 1969; Skerman 1977; Askew and Mitchell 1978; Le Houerou 1980; Cisse and Wilson 1985). These browse trees have been regarded as reserve forages for use during drought and the annual dry season. Generally, the quality of this "top" feed or browse is not high (Askew and Mitchell 1978), but they are useful for livestock survival. In some situations, native trees may have economic significance not only for high-quality forage but also for uses such as fuelwood, poles, and traditional medicines (Cisse and Wilson 1985). In the development of some scrub and woodland areas in Australia, for example, desirable trees such as *Brachychiton australe*, *B. rupestre*, and *B. populnea* have been preserved for drought feeding purposes.

Belts of indigenous trees have been preserved in native pastures to control erosion (Houghton 1984) and salinity (Hughes 1984), for livestock shade (Daly

1984), wildlife corridors, windbreaks, firebreaks, and other physical attributes for the long-term benefit of the environment and the domestic livestock (Burrows 1985; Burrows et al. 1986). Steep landscapes can be stabilized by the preservation of native trees in grazed and ungrazed situations. In monsoonal woodlands, moisture is not limiting during the wet season for tree and grass growth; however, lack of soil moisture in the long dry season is a serious limitation for grass growth (Mott et al. 1985). Even a low density of native trees in hot, monsoonal environments is of greater benefit to livestock than having no trees at all. In many of these native pastures, soils are grossly deficient in plant nutrients, especially nitrogen and phosphorus. The trees can act as nutrient pumps, recycling nutrients from soil depths to the surface layers. Nutrient accumulation under the tree canopy may allow nutrient-demanding grasses to establish and persist (Ebersohn and Lucas 1965).

Another excellent example of native trees enhancing the growth and persistence of a forage grass is that of lancewood (*Acacia shirleyi*) on the native lancewood grass (*Calyptochloa gracillima*) growing on the edge of lateritic red-earth tablelands in Queensland, Australia. The soil is very infertile and erodible when cleared. The *Acacia–Calyptochloa* combination is the most productive use of this land because the two species occur naturally on such soils and cattle relish the grass. The nutrients transferred to the grass and the shade from the nitrogen-fixing *Acacia* maintain a suitable environment for *Calyptochloa*, which may grow almost exclusively under the shade of the *Acacia*. The response may be similar to that of Texas bristle grass, which grows almost exclusively under trees and shrubs and generally has twice as much crude protein as other grasses (Everist and Alaniz 1982); shading may even enhance its crude protein content (McEwen and Dietz 1965).

Native trees and introduced pastures

In many countries, farms can still be found that have areas of standing native forest on shallow, infertile soils generally considered to have little potential for crop production. These areas usually are left as sources of fuelwood, farm timber, and salable timber, or are cleared completely for tree crops or pasture development. The importance of retaining trees to minimize problems of salt seepage and in preserving a timber supply has often been overlooked in agricultural development. Developing a forage system in such areas is possible and it can be of substantial benefit to the whole farming enterprise. An example of a native forest developed at minimal cost to improve pasture under the trees is the use of *Eucalyptus maculata – E. acmenoides* on a steep slope with shallow infertile soils at Gympie, Queensland. An improved pasture of Hamil grass (*Panicum maximum*) and *Archer axillaris* (*Macrotyloma axillare*) was successfully established from aerial broadcasting. The growth of the millable hardwoods was enhanced and the cattle benefited considerably, especially in the dry season, from the high-quality forage (Cook and Grimes 1977; Cook et al. 1984).

The rain tree (*Samanea saman*) is native to the humid rain forests of northwestern Venezuela. During the development of forest for improved pastures, the rain trees were preserved. These trees have been largely responsible for maintaining the high quality of the planted guinea grass (*Panicum maximum*) for milk and beef production (through the transfer of nitrogen) and the supply of nutritious pods for the animals. The use of tree legumes to enhance the production and quality of forage has been extended to forage systems in plantation crops (Gregor 1972; Thomas 1978; Watson 1983).

Plantation trees in forage systems

Improved pastures under plantation crops grown for food or industry have had benefits beyond that of supplying forage for livestock either in grazing management or in cut-and-carry systems. In the plantation-establishment years, forage management is such that the crops are not harmed by livestock or seriously set back by competition from the planted forage. Generally, cut-and-carry systems of harvesting the forage in the early years allow for flexible management so that crops and forage can be established rapidly. Grazing begins when the tree crops cannot be damaged by the livestock. Plantation crops and forage species can be combined in numerous ways and many have been reported (e.g., Thomas 1978; Humphreys 1978; Watson 1983). Tree crops supplying food and food products may be grown in enterprises ranging from small, self-sufficient farms to large commercial organizations. Other trees are grown for industrial products such as timber, pulpwood, fibre (kapok), oil, rubber, and medicines (e.g., *Dubosia* in Australia).

Nonleguminous trees have been used for mulch and forage; discussion here, however, is centred on nitrogen-fixing legumes that are usually associated with plantation crops. These plants offer a cheap source of protein for the livestock and nitrogen for crop fertilizer. Herbaceous and tree legumes alone or in combination can be incorporated into such forage systems. Nitrogen-fixing trees serve several purposes, including forage. When selecting such trees in a forage system, the needs of the farming–pastoral community, other socioeconomic factors, desirable features of the available tree legumes, and the urgency to implement programs using them in cropping and forage systems must be carefully considered.

Selection of tree legumes

There are many multipurpose tree legumes that could be incorporated into cropping and forage systems, ranging from small shrubs to tall trees. Attributes of tree legumes recognized as useful in forage systems are given by MacMillan (1935), Purseglove (1968), Gray (1969), Brewbaker et al. (1972), Skerman (1977), NAS (1979, 1980, 1983a, b, c, d), Brewbaker et al. (1982), Craswell and Tangendjaja (1985), Reid and Wilson (1985), and Brewbaker (1986). Several characteristics of tree legumes are considered highly desirable when establishing forage systems. Thornlessness and perenniality are prerequisites. The trees should produce high yields of edible material with rapid regrowth after cutting and be good-quality forage in terms of protein and mineral content, palatability, and digestibility. They should also retain leaf and edible plant parts of high quality in the dry season. Finally, the tree legumes should be relatively easy to establish and exhibit rapid, early growth.

Trees in a single tier

From past work and the availability of planting material, several tree legumes come to the fore for immediate use. The first is *Leucaena leucocephala*, which has been researched widely. There is a wide range of *L. leucocephala* cultivars, from shrubby forms to upright trees. Cultivar selection depends on the proposed management system. Because the tiny insect, *Leucaena* psyllid (*Heteropsylla* sp. poss. *incisor* [Sulc]) is a threat, resistant cultivars, such as the Hawaiian Giants (cv. K-527, K-538, K-584, K-591, K-636, K-658), are important (J.L. Brewbaker, personal communication). *Gliricidia sepium* is another tree legume used widely throughout the humid tropics for which much information is already available. *Leucaena* and *Gliricidia* have already been selected for the humid zone of Nigeria by Atta-Krah et al. (1985), who concluded from their studies that both these tree legumes are highly productive, contain significant amounts of nitrogen, establish well under tropical environments, and, therefore, are immensely suitable for the improvement of farming systems through maintaining soil fertility for crop production and increasing the availability of high-protein feed for small ruminants. The rapid early growth and other attributes of *Sesbania grandiflora* reported in Indonesia (Craswell and Tangendjaja 1985) and elsewhere (Skerman 1977; NAS 1979, 1980) make this tree legume worthy of immediate consideration for inclusion in forage systems research and development in both the humid and subhumid tropics.

The vigorous, tall-growing cultivars of pigeon pea (*Cajanus cajan*) are other forage legumes worthy of evaluation. Pigeon pea is a common crop throughout the tropics where it is used as food, forage, windbreak, ground cover, and fuel (Skerman 1977; NAS 1980). Although grown and used as an annual or biennial for pulse production, it can be maintained for up to 5 years for mulch and forage. Pigeon pea has been planted in rows between crops or sown mixed with the main crop. Because of its slow initial growth and suppression by shading, it is often sown with summer crops, such as maize and sorghum, to produce pulse and forage after the main crop has been harvested. Inoculation is not needed and some cultivars tolerate soils with excess salt, soluble aluminum, or manganese (NAS 1980). Pigeon pea has all the desirable attributes of a shrub legume for forage and mulch, but it is short lived. Rapid early growth of pigeon pea can be advantageous when it is planted with other, slower growing tree legumes. Planting a combination of tree legumes can also provide insurance against disease or pest damage that might attack one particular species.

Leucaena has been used widely in alley cropping in Indonesia, the Philippines, and many African countries. The management of *Leucaena* in alley cropping may differ slightly between countries and between farms. In the Philippines, *Leucaena* hedges are 4 m apart and pruned at 1 m every 6 to 8 weeks. The soft foliage and stems are used both as mulch for the companion crops and as livestock feed away from the crop area.

Whereas *Leucaena* could receive priority as permanent trees in alley systems for both the humid and subhumid areas, *Sesbania grandiflora* also deserves attention for similar areas. *Gliricidia sepium* is likely to be important for humid areas only.

Trees in multiple tiers

A high tier of tall tree legumes at densities of no more than 20/ha could be incorporated into long-term cropping and forage systems. Local trees may be preferred by farmer–pastoralist groups, as with *Acacia albida* in Malawi (Casey 1983). *Acacia auriculiformis*, *Erythrina poeppigiana*, *Samanea saman*, *Albizia falcataria*, and *Pterocarpus indicus* could serve useful roles as upper-story nitrogen suppliers to the cropping–forage systems.

For more intensive forage systems using leguminous trees, alley grazing and protein banks for supplementary grazing have been very successful. Again, *Leucaena leucocephala*, *Gliricidia sepium*, *Sesbania grandiflora*, and other quick-growing tree legumes have been used. The experiences with *Leucaena*, however, can be used as models for cultivated tree legume forage systems, which vary considerably from protein banks to alley grazing systems.

Leucaena in forage systems

In the tropics and subtropics, *Leucaena* has been used in many different ways in forage systems. Each system has strengths and pastoralists can choose the forage system best suited to their particular situation. System names may differ between countries, often because of the systems' flexibility. Sometimes systems can overlap or change with the seasons depending on the associated crop stage or forage requirement.

Intensive forage systems

Intensive forage systems involve dense stands of *Leucaena*, often irrigated, where intensive management is an essential element. The size of the operation may differ between countries and even between farms but the three following basic models are common.

Forage and protein banks

Naturalized *Leucaena* and high-density plantings have been used in cut-and-carry systems in many countries to supplement other forages available for intensive stall or corral feeding of livestock. Generally, harvesting continues throughout the year.

Livestock may also have access to all or a portion of the *Leucaena* paddock for grazing for short periods on a rotational basis with other forages. Native grass (Foster and Blight 1983) or sown grass pastures usually supply the major part of the feed requirement. Although this rotational grazing may continue throughout the year, *Leucaena* supplementation becomes more important during critical nutritional stress periods. Deferred use for such times is often practiced.

Leucaena–grass mixtures

Leucaena is established by broadcasting at relatively high seeding rates (5–10 kg/ha) with a companion grass (1–2 kg/ha). Rotational grazing to suit the *Leucaena* regrowth is used. A similar system has been used by researchers at the

Central Mindanao University in the Philippines where *L. leucocephala* cv. Hawaiian Giant K-8 was established as seedlings at 2-m spacing on the square, within a *Panicum maximum* stand. Set rotational grazing was practiced.

Irrigated *Leucaena*

Leucaena planted in rows 3–4 m apart with pangola grass between the rows has been used under irrigation and rotational grazing at the Kimberly Research Station in western Australia. The pasture, grazed at 4–5 steers/ha throughout the year, has given high animal production levels (D. Pratcheet, personal communication; Wildin et al. 1986).

Another irrigated *Leucaena* system in eastern Queensland involves high-density plantings at 1 to 1.5 m row spacings. The *Leucaena* can be machine harvested every 8–10 weeks for green feed or dried meal production. Intensive rotational grazing may also be practiced. In Australia, grazing such intensive *Leucaena* pastures demands that the ruminants be inoculated with 3-hydroxy-4 (IH) pyridone (DHP) with the detoxifying bacteria found in ruminants grazing *Leucaena* in Hawaii and Indonesia (R.J. Jones, personal communication; Partridge and Adams 1985).

Alley systems

Alley systems involve *Leucaena* or other forage tree legumes in defined rows with crops or other forages planted between the rows. There are four general alley systems.

Alley cropping

Leucaena is established in rows 4–20 m apart, depending on soil type, rainfall, associated crop, and farming practices. Crops are grown between the rows. Permanent tree crops may be involved; however, the discussion here focuses on annual cropping. In central Queensland, Australia, rows as wide as 20 m have been established with grain sorghum planted between the rows. The row spacing allows extensive cropping with wide planting and harvesting machinery while the *Leucaena* is becoming established. A grazed fallow is practiced and when the *Leucaena* is at least 3 m tall, perennial grasses are established between the rows and alley grazing is then practiced.

In the humid and subhumid tropics, *Leucaena* is planted in single or close double rows that are spaced 4–8 m apart. Annual crops are planted between these permanent *Leucaena* hedges. Generally, prunings are used as mulch–fertilizer. Some of the prunings are removed for livestock feeding away from the crop area (see Kang et al., this volume).

Some alley cropping systems have no fallow period because a following crop is established before the earlier crop is harvested. The crop stubble is used for mulch or removed for livestock feeding supplemented with *Leucaena* prunings. In other alley farming systems, livestock is allowed to graze on crop stubble, undersown legumes, and *Leucaena* rows during the fallow period.

Grazed fallow

Livestock access to the cropping area depends on the fallow period between crop plantings. The grazed fallow can be a matter of a few weeks to several years. The contribution of the grazed fallow to soil stability and fertility and to crop and livestock production is being studied (Atta-Krah et al. 1985). During the grazed fallow, one of the alley grazing systems is adopted.

Alley grazing – hedgerow system

In the alley grazing – hedgerow system, *Leucaena* is managed so that all forage on the bushes is completely accessible to the grazing livestock. For long-term alley grazing, a grass is established between the *Leucaena* rows. During the dry season, continuous grazing may be practiced; however, during the main growing period, rotational grazing is essential to allow a rest period for the *Leucaena* to recover from severe defoliation. A suitable rotation would be 2 weeks grazing and 6 weeks rest. More intensive grazing of shorter duration may be practiced but a minimum of 4 weeks rest is essential; 6–8 weeks is preferable. Intervals between grazing could be lengthened during periods of slow growth. Sometimes the pasture is rested to accumulate a bulk of high-quality forage for the beginning of the dry season.

When the interrow spacing is less than 5 m, *Leucaena* should be prevented from growing too tall so that grass and herbaceous pasture legumes growing between the rows receive sufficient light. When there is excessive shading, pruning or lopping will bring the *Leucaena* back to a manageable grazing height.

Alley grazing – tree system

In the alley grazing – tree management strategy, *Leucaena* is encouraged to grow into a multistemmed tree. This system is generally not associated with a cropping fallow but with permanent pastures established between the rows. The favoured cultivars are Peru and Cunningham, shrubby cultivars that naturally branch at the base. Row spacings should be at least 7 m to allow sufficient light to penetrate for vigorous grass growth. The amount of *Leucaena* forage from the trees and seedlings may not be as high as in the hedgerow system; however, this system is productive and stable, and provides highly nutritious feed, shade, and organic fertilizer (Wildin 1986) compared with other sown pastures that demand higher management inputs for persistence and productivity.

The alley grazing – tree system has allowed rapid commercial adoption of *Leucaena* in Australia, especially in semiintensive and extensive enterprises (Wildin 1981, 1986). *Leucaena* offers high-quality forage in the critical dry season. It can play an important role in augmenting low-quality native pastures (Miller et al. 1986) in savannas with distinct dry seasons. The management in such systems can be quite varied; at the drier end of its range, wide-row alley grazing between *Leucaena* growing as trees would be most appropriate.

Animal production

Improved animal production from planted forages is usually expressed in terms of higher stocking rates and higher live-weight gains per animal per year than those obtained on native pastures. Planted forages complement or supplement other available forages. The value to livestock of the high-quality forage from *Leucaena* and other fodder tree legumes in the dry season is well recognized. For beef cattle, high stocking rates and daily live-weight gains up to 1 kg/head have been achieved on *Leucaena* pastures in central Queensland, Australia (Foster and Blight 1983; Wildin 1986). Breeding cows have grazed on *Leucaena* as a supplement to native pastures during the dry season. The benefits are difficult to assess in terms of improved breeding performance because no comparative work has been done. *Leucaena* is known to improve the live weight of cows at the end of the dry season. This suggests that the cows would be gaining weight quickly early in the wet season and conception rates would be high. In this respect, *Leucaena* could give further gains to animal production over that gained from native pastures.

Conclusions

Indiscriminate forest clearing in the world, occurring at the rate of 10 to 20×10^6 ha/year, will make native fodder trees a thing of the past for many countries (Brewbaker et al. 1982). The Americas and Indonesia will have most of the remnants, a mere 25% of the forests that covered the tropics a century ago. However, the addition of legume shrubs and trees could have a major impact in fodder intake and nutritional value for the vast grazing and cropping areas of the natural and induced savannas of this zone. Multipurpose legume trees that provide fodder and fuelwood and have beneficial effects on the environment, humans and their livestock will be of value. Where adapted, *Leucaena* (especially the psyllid-resistant cultivars), *Gliricidia*, *Sesbania grandiflora*, and the forage types of *Cajanus cajan* can be immediately incorporated into alley grazing systems. The many advantages of tree legumes have been recognized, and they deserve more research and development.

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Part 4

On-Farm Alley Cropping and Farming Research

On-farm research methods for alley cropping

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Abstract — On-farm research methods, which follow a sequence of events until the technology is ready for adoption by farmers, can be applied in alley cropping research and development. Well-focused, on-farm research consists of sharply defined objectives, criteria for site selection, identification of target groups, accurate descriptions of the farming system, constraints and opportunities, appropriate design of on-farm trials, and a well-established, on-farm testing program. As a composite technology, alley cropping needs to be tested under real farm conditions. On-farm trials can be researcher managed or farmer managed, depending on the complexity of the technology and to what extent the technology has been tested under farmers' field conditions. Researcher-managed trials are usually conducted in the early stages of alley farming research and provide information mainly of a biological nature. Farmer-managed trials usually give indications of both the biological and socioeconomic aspects of alley cropping applications.

Introduction

Before any new technology is adopted by farmers it must be tested under real-farm conditions. The final test for the success of a new technology or innovation is adoption by a large number of farmers in a target area. On-farm research (OFR) can effectively show whether a technology can be transferred and adopted by farmers or whether modifications are required. Through OFR, new and improved farming methods are continuously being tested and evaluated by researchers in collaboration with farmers. Like any other new technology, alley cropping must be tested through OFR. As a new technology, it must be technically and economically feasible and superior to the existing technologies it is designed to replace. This paper generally describes OFR methods and how they can be used to conduct on-farm trials for alley cropping. Because the Farming Systems Programme of the International Institute of Tropical Agriculture (IITA) has only recently begun OFR on alley cropping, discussion in this paper deals mainly with methods and guidelines rather than with results.

Components of on-farm research

Site selection

A research site should represent land types or production environments that occur extensively in target areas. The site may be divided into "recommendation domains." A "recommendation domain" is a set of farmers who cultivate land with similar features and who have access to similar resources (Tripp 1982). For example, in the derived savanna of southwestern Nigeria, two recommendation domains can be distinguished: farmers who cultivate the forest and savanna fields and farmers who cultivate only the savanna fields. The second recommendation domain has shorter fallow periods (Palada et al. 1985). For both groups, alley cropping is feasible; however, the benefits and impact may differ.

Other criteria are important when selecting a research site: farm size; major cropping or farming systems and potential for improvement; and infrastructure quality (i.e., roads, markets, transportation, credit, farm inputs, and accessibility). The selection of sites for alley cropping trials should consider land type (upland, lowland); soil (fertility, depth, texture, pH, organic matter); topography and slope; climate (rainfall); agronomic and socioeconomic factors; and the farming system (permanent, semipermanent, bush fallow). The researchers should ensure that the sites selected conform with the definition of the target groups and land types. Ngambeki and Wilson (1984) used the following six criteria to select a site for their alley cropping trial: yam–maize producing area; size of the active farming community; shortage of staking material; soil fertility problems; quality of marketing facilities for yam and maize; and accessibility.

Site description

After the research site is selected, the research team should describe the area's existing farming systems, normally through an informal exploratory or diagnostic survey that may last 1 or 2 weeks. Preliminary information is collected before the survey starts. This preliminary information forms the basis for determining what data should be collected.

The exploratory survey provides a description of the area's farming systems and identifies target groups of farmers. It also tries to identify the major constraints operating in the systems and the farmers' goals and aspirations. This information is then used to design appropriate interventions to the system (Mutsaers et al. 1986).

The survey team should include as many relevant disciplines as are available; in most cases, however, the minimum size of the team is two — an agronomist and a social scientist. In areas where constraints are related to soil problems and livestock, these disciplines will be included in the survey team. These four disciplines should be represented in on-farm research in alley farming.

The following areas should be included in the survey information: physical environment; field history, particularly the length of the fallow period; cropping techniques, with particular reference to soil fertility maintenance; postharvest practices such as utilization of crops, crop residues, and by-products; livestock systems, including species, feeding regimes, and interaction with cropping systems;

socioeconomic aspects, including access to land and tenurial arrangements, sources, and distribution of labour, peak and slack periods and bottlenecks, and sources and principal uses of cash and credit. A knowledge of external support structures such as the availability of extension and input delivery systems is also useful.

Alley farming may have a higher chance of being accepted in areas with soils of low fertility (Wilson and Kang 1981; Kang et al. 1984), a sloping topography (Parera, this volume), with livestock as a component of the farming systems (Ngambeki and Wilson 1984; Atta-Krah 1985), and where farmers are landowners (Francis, this volume).

In an exploratory survey of two villages in the derived savanna near IITA, inherent low fertility of soils in the area is one of the major technical constraints (Palada et al. 1985). This was observed in both savanna and forest fields where the dominant soils are highly eroded and sandy, with shallow top soil and low organic matter. The team proposed two interventions for soil fertility improvement and maintenance. Alley cropping was proposed as a long-term solution with the use of fertilizer recommended as a short-term solution. The major cropping system in this area is a maize and cassava intercrop.

Design of on-farm trials

The design of on-farm trials for alley cropping should be based on the major problems and constraints observed during field visits, surveys, and farmer interviews. The trial must be directed at a specific problem with well-defined objectives. They should test interventions designed to solve previously identified constraints and evaluate the suitability and feasibility of the proposed solution. Suggested guidelines for developing and designing on-farm trials should include reasonable gains in yield acceptable to farmers. It should prove beneficial to soil and environment, fit the farmer's resources (capital, labour, land, cash, and management), be adapted to the site's physical and biological conditions, be stable over time and fit in with other management practices, be simple enough to be understood, and be socially acceptable (Zandstra et al. 1981).

An example of the on-farm trial design for alley cropping in the Alabata/Ijaiye pilot area near Ibadan is presented here. The specific objectives of this trial are to determine the agronomic and economic feasibility of alley cropping under field conditions; to establish field crops of maize and cassava between alleys of woody shrubs and determine yields and productivity; to monitor soil fertility changes over time in plots with alleys compared with natural fallow; and to determine the length of cropping and fallow periods.

There are two treatments: first, maize and cassava (farmer's system, no alleys) and, second, maize and cassava with *Leucaena* alleys at the recommended spacing of 4 m. The first treatment serves as a control. Farmers establish maize and cassava using traditional methods. In the experimental treatment, farmers establish hedgerows of woody shrubs and grow food crops (maize + cassava) between the alleys using their own varieties and management practices. The only intervention to the farmer's existing system is the introduction of woody shrubs. Each block contains the two treatments and represents one farmer and one replication. A minimum plot size of 1 000 m^2/treatment is required for the collection of economic data.

Selecting an appropriate design for on-farm experimentation can be difficult because of variability between fields. The physical and socioeconomic environment of the research area may also place constraints on the design of the trial. Therefore, in on-farm trials, careful selection of design to minimize variability and reduce experimental error is important. Some points to consider in designing on-farm experiments are the heterogeneity of many fields with respect to slope, drainage, fertility, and previous cropping systems; the small size of many farms and the need for large plots for farmer-managed tests; the limited capability of randomizing treatments; a limited number of plots in a single farm; and differences in management practices for a single crop.

Simple experimental designs for on-station trials may be used for on-farm trials. The specific design to be used will vary according to the complexity of the experiments. Trials involving one or two levels using basic field designs are recommended as a first step. As the research team becomes more experienced, the number of factors and levels can be increased. The most common experimental designs used for on-farm trials are the randomized complete block, randomized incomplete block, and factorial designs.

On-farm testing

After appropriate trials have been designed and planned, the research team should organize a field-testing strategy. Before this, however, testing farmers should be taught how to execute and manage the trial. It should be made clear to them that the trials are experiments, not demonstrations. Therefore, they should be aware that experiments are sometimes subject to the same failure as their own crops. Failure because of weakness in design or management should be discussed between researchers and farmers so that corrections and modifications can be made in the early stages of the research process. When failure is due to the effects of the treatment, the farmer should be compensated either in kind or cash.

Technologies for on-farm testing

A technology is any factor or a combination of factors employed in crop production to improve the farming system's productivity. Examples of technologies include cropping techniques, use of chemicals, implements, and new crop varieties. For on-farm testing, there are three technology classes: single component or elementary, composite, and package (Mutsaers 1984).

Single-component technologies cannot be broken down into separate elements. They can be applied without requiring additional changes in the farming system. Examples of single-component technologies are a disease-resistant plant variety or fertilizer application. In single-component technology trials, new technologies are compared with the farmer's own in an otherwise unchanged system. Such technologies are based on the assumption that improvements are possible in an existing system, without changing the whole system drastically. Such trials may be particularly useful at the start of an on-farm research program, when the researchers have insufficient knowledge of the system to venture into more complex technologies or packages.

Composite technologies are made up of several interdependent elements that cannot be considered in isolation. An example is alley cropping, which consists of the following elements: tree establishment and management, mulching to maintain and improve soil fertility and crop production, soil conservation, animal feed, and socioeconomic considerations. These elements are closely interrelated: if one element is missing, the benefit expected from the technology is not achieved. For example, in alley farming, the trees must be pruned to provide mulch and fodder. Use of prunings for fodder reduces the quantity available for mulch and, hence, adversely affects crop yields. Extending pruning intervals will result in more tree foliage for forage, but increased shading will be detrimental to crop production.

Package technologies are a combination of several technologies. Each or part of the elements in the package may have its own effect, but the elements may be combined to exploit a synergistic effect. The conventional "improved production packages" for single crops that have been produced extensively by experiment stations fall into this class.

The simplest package trials are those that test a combination of component technologies imposed on an existing cropping system or pattern. In a maize–cassava intercropping system, this could be mutually compatible improved maize and cassava varieties at a recommended plant arrangement with fertilizer and herbicides. The package is compared with the farmers' maize and cassava system. Additional treatments can be included in an "add-on trial," which allows the added effect of each additional set of technologies to be assessed.

Researcher-managed trials

Researcher-managed trials are used to evaluate the performance of new technologies or a specific management component and to determine the optimum rates or level of available technologies in farmers' fields. These trials provide close control and a high degree of accuracy by reducing variability and are managed and executed by the researcher. The farmer is minimally involved.

On-farm trials managed by researchers can be exploratory, site specific, confined to a region, or located in several places (Hildebrand and Poey 1985). Researcher-managed trials will, however, provide less information on the acceptability of the intervention to the rural community.

Exploratory trials are used when little is known about an area or possible effects of a specific type of technology. They can be considered complementary to, or part of, characterization, and usually precede site-specific or regional trials. Exploratory trials normally provide more qualitative than quantitative information about several factors. Frequently, two levels of each factor are included and few replications are used. The most common designs are the $2n$ factorial and plus or minus trials. An exploratory trial can sometimes be superimposed on farmers' fields without special preparation of the experimental area. Exploratory trials are similar to on-station trials in terms of design; however, they are conducted on farmer's fields.

A good example of an exploratory trial with alley cropping is the introduction of woody species in an area where the species have not been grown before to determine their compatibility with annual food crops grown in the alleys. The woody species can be superimposed on the existing cropping pattern of the farm.

Site-specific trials are often designed to search for potential or maximum effect of a technology. Experimental cultivars, for example, are frequently screened under conditions that do not limit the expression of genetic potential. This potential, however, is measured only for the one location — the experiment station. To obtain more useful information, two or more farm locations can be used with the same type of experimental design and analysis to measure independently "deviations from potential" at different locations. Analysis of data from site-specific trials is similar to that of yield gap analysis (see Gomez and Gomez 1984).

Because they are usually complex, with a relatively large number of treatments and replications, site-specific trials are only conducted in a limited number of locations. Information sought is agronomic and not socioeconomic, so plots are small. Possible sources of variation, such as soil fertility, are frequently controlled at the same levels used on the research station. Participation of the farmer is minimal.

An example of a site-specific, researcher-managed trial is that of alley cropping with *Leucaena* and *Gliricidia* in the derived savanna of southwestern Nigeria. This trial is designed to demonstrate the potential of alley cropping in regenerating soil fertility and control of a persistent weed, *Imperata cylindrica*, which are specific problems in the area. Three treatments are used: maize–cowpea, maize–cowpea with *Leucaena*, and maize–cowpea with *Gliricidia*. The maize–cowpea treatment serves as a check plot (no alley). The trial can be set up in a randomized complete block with two locations as replications.

Regional trials consist of a set of similar trials conducted in a region previously identified as a recommendation domain. Their main objective is the evaluation of data from on-farm and on-station trials to define the interaction of technology with environmental conditions, from both agronomic and economic viewpoints. Regional trials may result in confirming the homogeneity of a targeted area or suggest that, to be relevant, the area be divided. Recommendations for treatments for farmer-managed trials should result from the analysis and interpretation of regional trials. Regional, on-farm trials in alley cropping in Nigeria are a good representation of this type of researcher-managed trial. In each of the humid and subhumid zones of Nigeria, trials are being conducted in 6–10 locations by IITA and the International Livestock Centre for Africa (ILCA) in collaboration with national institutions.

Farmer-managed trials

Farmer-managed trials provide the opportunity for the farmers to manage and evaluate one or two promising treatments from regional trials. It is only at this stage that the acceptability of an intervention can be determined. Large unreplicated plots of at least 1 000 m^2 should be used. This enables the farmers and researchers to compare the treatments with their own practices. A check plot with these practices can be included in the design. In practice, the check plot serves the researchers more than the farmers. If researchers wish to measure the results of the farmers' practices, they can also sample the farmers' fields. However, agronomic data (e.g., plant density and yield) and economic data (labour use, costs, and returns) of the farmers' practices must be kept. It is desirable to have at least 30 farmers in these trials in a recommendation domain. A team composed of an agronomist, a socioeconomist, and two research technicians is sufficient to handle data collection from 30 farmers.

Data collection, monitoring, and evaluation

The long-term purpose of monitoring and evaluation is the better understanding of how innovations perform in farmers' fields under farmer management and whether the innovations are acceptable or, with modification, can be made acceptable to farmers. Monitoring and evaluation can also identify problem areas related to technology and provide feedback to on-station researchers for the refinement of the technology. Data are needed each year for the annual design exercise, when the research team decides which trials should continue, which should be dropped, and whether the design or operational procedures of each trial should be modified.

Good monitoring and evaluation include accurate descriptions of cooperating farmers and their fields; exact monitoring of field operations by enumerators under close supervision; informal farmer interviews by the researchers; and closed sequence questionnaires administered at the end of the season to farmers by supervised enumerators. In on-farm research, four types of data are usually collected: physical (including climate and soil), agronomic performance of crops or technology, economic performance of crops or technology, and social acceptability.

Physical data

Data on rainfall are collected daily and reported on a weekly basis. Other climatic data such as solar radiation, temperature, and evaporation can be monitored from the nearest weather station. For each plot where a trial is established, data on land type and soil characteristics should also be collected. At the end of the cropping year, the data are summarized and analyzed to evaluate crop performance, cropping systems, or a technology.

Agronomic data

There is a wide range of agronomic data that can be collected from trial plots and farmers' plots. The research team should decide which information is necessary and plan the data-collection process accordingly. Data collection requires frequent visits to trials and careful observation; it is, therefore, essential to identify the important points for each trial. In alley cropping trials, data such as hedgerow establishment, height, biomass production from prunings of woody species, and regrowth are as important as yield data from annual food crops grown in the alleys. Where prunings are removed for animal food, the quantity must be measured. It is important to prepare a field book for agronomic data; this book should contain all information about the trial, soil, crop, and field operations.

Economic data

Two sets of economic data are usually collected. The first set concerns only those plots where the trials are established. These trials may consist of two or more fairly large (1 000 m^2) treatments to get reliable labour data. The other set of data is gathered from the farmers' untreated plots. These data are useful for farm model studies. In the first set of data, partial budgeting and simple cost and returns analyses are used to evaluate the technology's economic performance. An example of the economic evaluation of alley cropping is reported by Ngambeki (1985).

Social acceptability

The ultimate test of social acceptability of an intervention is its adoption rate. Many factors come into play to determine acceptability. Successful on-station trials may not be adopted by farmers, who may have different opinions on what are positive changes. Interventions that are successful under one social system may fail under another. Trials managed and executed by farmers are essential to test acceptability (see Atta-Krah and Francis, this volume).

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The role of on-farm trials in the evaluation of alley farming

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Abstract—The role of on-farm research in the evaluation of alley farming requires two distinct types of trials: those concerned with the refinement of the system and the assessment of its relevance and acceptability to farmers and those aimed at the collection of technical and productivity data under farm conditions. The first type of trial is concerned with the evolution and definition of the system; therefore, it must be implemented at an early stage, as part of the development of the technology, and must precede the collection of technical data. Feedback from both kinds of trials is essential to ensure the relevance of on-station research. The close involvement of extension is required for the successful implementation of this approach.

Introduction

In farming systems research, on-farm trials play a key role in the development and validation of agricultural technologies. On-farm research ensures that technologies developed on-station are relevant to the resource-poor farmers, who are generally the potential adopters.

On-farm trials have been classified into many different types, which represent a sequence of procedures for the testing of technologies under farm conditions. A number of different schemes have been proposed (Matlon 1982; Zandstra 1982; Hildebrand and Poey 1985). The sequence is generally defined in terms of the farmer's increasing involvement in managing and evaluating the technology. Three stages are generally identified (Fig. 1): researcher-managed, joint researcher- and farmer-managed, and farmer-managed on-farm trials. Moving through this sequence, the decreasing involvement of the researcher in the management of the technology is accompanied by changes in trial design (which are simplified to include smaller numbers of treatments and replications), in types and methods of data collection and analysis, and in methods of interpretation and evaluation.

This paper, which draws upon the experiences of some 5 years work at the Humid Zone Programme (HZP) of the International Livestock Centre for Africa (ILCA), considers the role of on-farm research in the development of alley farming. The general thrust of this paper is to underline the critical importance of on-farm work in the design of technology acceptable to farmers; it is also argued that the

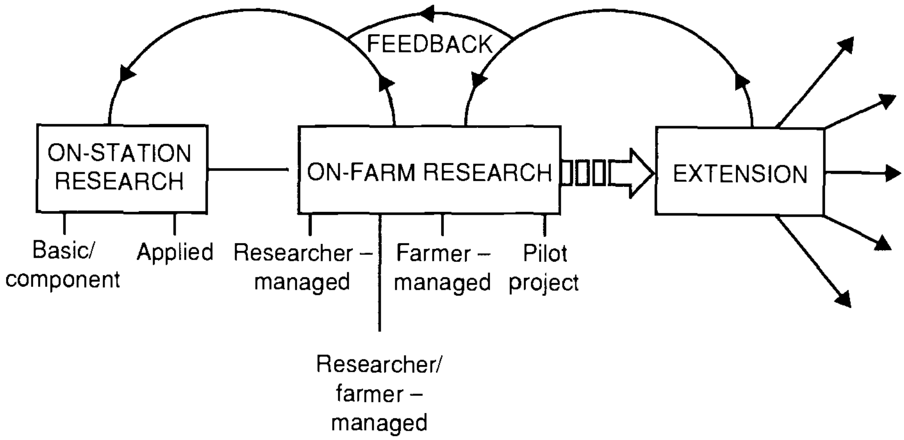

Fig. 1. The link between research and extension involves various stages of on-farm research.

tenure of alley farming as an enterprise requires some modification of the standard sequence of trials. After a brief description of the humid zone, the properties of alley farming as a system and their implications for the conduct of on-farm work are discussed. This is followed by a discussion of ILCA's on-farm research in alley farming. The final section presents some general conclusions about appropriate methods for the evaluation of alley farms in farmers' fields.

Some general considerations

The purpose of on-farm trials is to obtain information about the performance of a technology under farm conditions. Two kinds of information may be distinguished. The first, type 1, is the quantification of the technical, biological, and economic implications of an intervention. Such data are obtained from trials with standard designs, the execution of which requires a high level of researcher involvement. Type 2 information, in contrast, is concerned with the farmer's evaluation of the technology in terms of its relevance, workability, and acceptability. Obtaining this kind of information requires that the farmer controls, manages, and uses the technology. The researcher's role is limited essentially to observing farmers' responses, finding out reasons for specific farmer modifications and activities, and identifying problems and opportunities associated with these activities. Such data are generally qualitative; in some cases, however, quantitative assessments can be made by scoring for specific parameters across the total number of farms.

Two properties of alley farming have critical implications for on-farm research. The first is that alley farming is a system that involves and links a number of farm enterprises. In this, alley farming differs from technologies such as improved varieties or fertilizer, which involve only a single component. The second is that the planting and management of the trees implies changes in farmer behaviour. In the case of the on-farm testing of single-component technologies, both type 1 and type 2 information may generally be collected from the same trial. The flexible and innovative nature of alley farming means, however, that different kinds of trials are required to collect these kinds of information.

As a system, alley farming links tree planting and management, crop production, land and soil management, and livestock husbandry. The trees may be used in a number of ways. Foliage may serve either as mulch for any arable crop or as feed for ruminants. The wood may be used as staking material or firewood. The products of the trees may be allocated in many ways — there is nothing integral to the system that determines, for instance, the respective proportions of the foliage that should go to crops and livestock.

The systems nature of alley farming has implications for the collection of both quantitative, biological type 1 data and sociological type 2 data. The fact that the system impinges on a number of different enterprises, makes the collection of agronomic (type 1) and economic data problematic. On-farm trials for obtaining the technical coefficients of the system on farmers' fields can only be carried out under fairly strictly controlled conditions. Thus, variables such as the proportion of foliage used for mulch and for feed, the timing of tree cutting, crop type, variety, and management would all need to be controlled. Furthermore, the experiment would need to be extended over several years to allow for the long production cycle that results from the combination of trees, long-term changes in soil fertility, and livestock.

Although the composite nature of alley farming makes the collection of type 1 data problematic, at the same time, it makes the collection of type 2 data critical. Flexibility is inherent in the system and this means that the farmers have various choices in the way they use it. These choices will be made based on production objectives and resources.

The novelty of the system is another reason for the importance of type 2 data. Although farmers are familiar with the management of trees in the context of a bush-fallow system, the adoption of alley farming implies a number of innovations in farming practice. These include planting and establishing trees within arable farms, their management for mulch and fodder production, cutting and carrying feed for animals, and altering land use and rotation patterns. Moreover, the issue is not simply one of managerial innovation and the acquisition of new skills. In adopting a new system, attitudinal, sociological, and institutional factors (such as the distribution of the benefits derived from the technology among household members or the implications of land tenure systems) may also intrude (Francis, this volume). A further consequence of the relative novelty of the system is the need to evolve and institutionalize effective extension strategies for the technology.

Taken together, these considerations dictate that different kinds of trials are required for the collection of type 1 and type 2 data. Furthermore, given the critical importance of type 2 data in the development and evaluation of the system, it is argued that type 2 trials must precede those for type 1 trials.

Two kinds of trials may be distinguished in ILCA's program of on-farm alley farming research. These correspond to the two categories of data. In this paper, the two types of trials will be labeled "developmental" and "experimental." Within the developmental phase, three stages may be distinguished. Figure 2 illustrates schematically the relationship between these kinds of trials. The first stage (1981–82) comprised exploratory trials; the second stage (1983–84), intermediate trials; the third stage (since 1984), a pilot research and extension project.

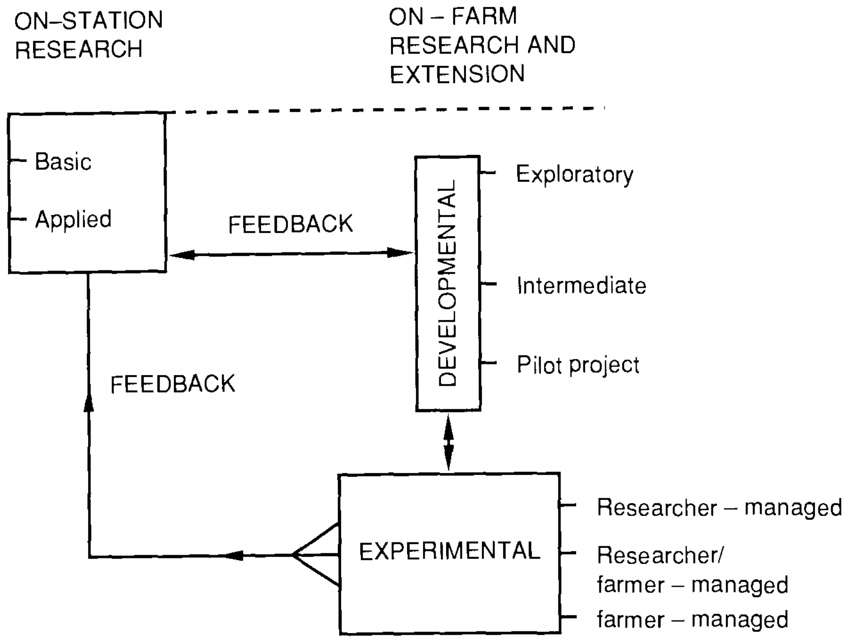

Fig. 2. The linking of on-station and on-farm alley farming research.

Information gained from these trials led to the progressive refinement of the alley farming system. With the technology's development, researcher involvement in managing the trial was allowed to decrease to allow farmers more scope.

Exploratory on-farm trials

Exploratory on-farm trials, which began in 1981, represented the first attempt to have alley farms established on farmers' fields. The trials addressed basic questions about the design of the technology and its viability under farm conditions. In that year, two alley farms were planted in the Badeku area some 30 km east of Ibadan. In 1982, three more alley farms were planted: another in the Badeku area and two near Fashola, to the west of Oyo and some 60 km north of Ibadan. The planting and management of these early farms was largely carried out by ILCA. One of the first two farms was planted on fallow land and no crops were planted there. This farm was worked collectively, with labourers provided through an already established farmer cooperative association. Difficulties were encountered in mobilizing farmers for collective work as the nature and distribution of any benefits were uncertain and offered little incentive for individuals. Furthermore, the idea of improved fallow was an unfamiliar one and there was reluctance to invest labour in its management. (Such management is not traditionally practiced in the area.)

These exploratory trials identified the household as the most effective unit of management and indicated the advisability of integrating browse tree management with that of arable crops. The early trials also indicated problems with the establishment of *Gliricidia*. The cost, in terms of time and resources, of obtaining, transporting, and planting *Gliricidia* from stakes was extremely high. This led to the initiation of on-station research on the establishment of *Gliricidia* from seed.

Intermediate on-farm trials

Intermediate trials gave researchers insight into a farmer's ability to manage alley farms. ILCA's involvement in planting and initial management was considerably less than in the earlier stage, and farmers were encouraged to contribute to the system's development by modifying it according to their individual circumstances and requirements. In 1983, 12 alley farms were established on farmers' fields with researcher–farmer participation in the Fashola and Badeku areas. Both *Leucaena* and *Gliricidia* were established from seed.

The two tree species grew well under farm conditions. The level of management on the part of farmers was generally satisfactory. Some farms in the Fashola area were cultivated by plough, showing that the system was compatible with mechanized tillage. Two farmers successfully used fire to clear the land between the alleys before cultivation at the end of the dry season. Another farmer showed how much could be incorporated during ridge movement by placing prunings in furrows and splitting the old ridges over them. As well as demonstrating the system's flexibility under farmer management, this phase of trials also indicated the initial size of alley farms that was acceptable and manageable. Sizes of farms established by farmers ranged from 0.2 to 0.4 ha, with a mean of around 0.3 ha. This phase also led to the development of criteria to monitor alley farms on farmers' fields. In addition, farms established at this stage could serve as demonstration plots for the next stage of on-farm work.

Although participating farmers managed their alley farms imaginatively and successfully, the system was not adopted by other area farmers. Diffusion would have been unlikely at this stage for three related reasons. First, ILCA's continued involvement in managing and monitoring the trials did not encourage other farmers to regard the technology as one to be taken up without similar assistance. Second, the program was oriented to individual farmers rather than to the community as a whole. Third, there was no extension involvement at this stage. These findings indicated two requirements for the effective dissemination of the technology: the need for an approach at the community level and the provision of an extension element specifically directed at alley farming.

The pilot project

The third stage in on-farm testing was the initiation of a pilot project in which the farmer controlled and was responsible for the alley farms. This project was executed in collaboration with the Nigerian Livestock Projects Unit (NLPU) and the methodology is described by Atta-Krah (1985). ILCA input during this phase was largely limited to providing browse-tree seed and advice on planting and management. The purpose of this stage was to assess the relevance, workability and acceptability of the system to farmers and to allow its further development by farmers under a range of management and environmental conditions.

To avoid the possibility of farmer dependence arising from a high level of researcher involvement in the earlier stages, a new site was selected for this third stage. With occasional visits from project staff, farmers in the exploratory and intermediate stages were left on their own to continue managing their alley farms. As previously indicated, these farms will serve as demonstration and training units for the third stage of the on-farm work. The criteria for site selection for this third stage were evidence of active involvement in arable farming and interest in small ruminant husbandry. After extensive traveling and aerial surveys in two local government areas of Oyo State, the adjacent villages of Owu Ile and Iwo Ate, situated some 20 km northeast of Oyo in Ejigbo and Ogbomosho Local Government Areas, respectively, were selected. The villages had the advantage of being situated in the transition zone between forest and derived savanna, many of the inhabitants farming land in both ecological zones.

After the villages were selected, village chiefs and other figures of authority were contacted; through them, meetings were organized to present and discuss the proposed project. Samples of browse and browse seed were displayed and posters depicting the various stages of tree establishment were distributed to the farmers. The commitments and responsibilities of farmer and researcher, in particular regarding funding and credit, were clearly outlined to forestall the raising of false expectations. No credit was involved in the project.

Visits were organized for interested farmers to the earlier trial sites to enable them to see alley farms established on farmers' fields similar to their own. This gave them an opportunity both to see what alley farming involved and to exchange ideas with farmers who had already adopted the system. Following these visits, 45 farmers in Owu Ile and 33 in Iwo Ate registered to participate in the project. The land on which farmers intended to plant the trees was inspected to assess its suitability. Many farms were rejected because of poor farm management or intense shading from tree crops. An observation sheet and a short questionnaire were filled out for each farm to provide baseline information.

Meetings were organized with farmers to discuss planting arrangements and techniques; planting depth, seeding rate, and the spatial and species arrangement of the trees with respect to arable crops were detailed at these meetings. Subsequently, planting demonstrations were organized at both villages. Tree seeds, 450 g each of *Leucaena* and *Gliricidia*, were distributed to the farmers after the demonstration. Most of the farmers planted their farms within 4 weeks of the demonstration.

Monitoring and extension were essential elements in the project. An extension worker seconded from the Oyo State Ministry of Agriculture through the NLPU was trained by ILCA and based at the project sites (Owu Ile and Iwo Ate). This worker was involved in all operational activities and given special responsibility for advising farmers on the management and utilization of alley farms. Project monitoring was coordinated by an ILCA postdoctoral research fellow and data were routinely collected by two senior technicians who were assigned full-time to the project and were responsible for collecting agronomic and socioeconomic information. The monitoring program included fortnightly visits to all alley farms. At each visit, information was collected on the condition of the trees, food crops planted, activities carried out since the last visit, the general condition of the farms, and the farmers' perception of the system.

A baseline socioeconomic survey was conducted for all households in the villages. Information on household composition, occupation, and livestock ownership was collected. A project on the potential involvement of women in alley farming was also undertaken. The data collected were meant to define the socioeconomic characteristics of the potential client group (Okali and Cassaday 1985; Cashman 1986).

All alley farms were evaluated by researchers at 6-month intervals. Attention was given primarily to the establishment and general condition of the trees. On these visits, farms were scored with ratings ranging from 1 (poor) to 4 (excellent) according to the quality of tree establishment.

Project evaluation

At the pilot project stage, critical decisions about the establishment and management of the alley farms were left to the participating farmers. This resulted in the establishment of farms of various sizes on soils of varying fertility. Variations in soils and management resulted in variations in the growth and establishment of trees. Tree performance was also influenced by the crops or crop combinations grown between the rows and the cropping rotations followed. The utilization and management of the trees was, in turn, influenced by how far the farms were from the villages.

The number of factors influencing the performance of the trees makes the comparison of farms on the basis of any single factor impossible. The following analysis groups farms on the basis of several criteria and compares the mean evaluation scores of these groups (i.e., the average of the mean evaluation score for each farm in the group), to measure tree performance.

Ecology

As previously noted, Owu Ile and Iwo Ate fall within the transition zone between forest and savanna. Forest farms predominate around Owu Ile; most of the Iwo Ate land extends into the derived savanna. Shading was a problem in the case of some forest farms. However, soils in the forest areas are generally richer than those in the savanna; this would appear to have compensated for any shading effects. Overall, the mean evaluation score for forest farms as a group was not higher than that for farms in the savanna (Table 1). Clearly, viable alley farms can be established in both environments.

Table 1. Mean evaluation scores against site ecology of all 1984 alley farms.

Ecological zone	Number of farms	Mean (±SE) score
Forest	36	2.6±0.02
Savanna	26	2.6±0.03

Community

There was a marked difference between the two communities in the quality of alley farm establishment. The mean evaluation score for farms in Iwo Ate was higher than that for Owu Ile (Table 2). The likely explanation for the better establishment of the farms at Iwo Ate is the higher degree of motivation shown by the farmers in this area. This is probably linked to the manner in which contacts were first made with the villages. Whereas Owu Ile was approached by ILCA to participate in the project, the initiative for Iwo Ate's participation came from the farmers. Iwo Ate farmers have, in general, shown more interest in, and enthusiasm for, alley farming than their counterparts in Owu Ile.

Men and women

Women own or manage a large proportion of the small ruminants in southwestern Nigeria and are responsible for the supplementary feeding that is provided in the traditional management system (Fig. 3). They also engage in agricultural production. The potential benefits of alley farming for women, therefore, seem high (Youdeowei 1984). Although many of the alley farms in the highest evaluation category were those of women, on average, farms established by men scored slightly higher (Table 3). This is probably a reflection of the competing demands on women's time. In addition to farming, women are generally involved in food processing and marketing activities (Okali and Cassaday 1985).

Farm management

The level of farm management would appear to be the most important factor determining tree survival and successful establishment (Table 4). Weeding in the early stages of tree establishment is particularly crucial: seedlings that are relatively slow growing are adversely affected by competition from weeds. Tree seedlings overgrown by weeds may also be unwittingly uprooted in the course of weeding, especially when hired labour is employed. This created gaps in many rows and resulted in the complete loss of trees in a few farms.

Table 2. Mean evaluation scores against village of farmers of all 1984 alley farms.

Village	Number of farms	Mean (±SE) score
Owu Ile	33	2.50±0.02
Iwo Ate	29	2.80±0.03

Table 3. Mean evaluation scores of male and female farmers of all 1984 alley farms.

Gender	Number of farms	Mean (±SE) score
Male	51	2.66±0.02
Female	11	2.54±0.07

Fig. 3. Farmer-managed alley farm. Women farmers with *Gliricidia* hedgerows in southwestern Nigeria.

Table 4. Mean evaluation scores (weighted) of number of weedings for all alley farms.

No. of weedings observed[a]	Owu Ile		Iwo Ate		Overall mean
	No. of farms	Mean score	No. of farms	Mean score	
1	5	2.18	0	—	2.18
2	6	2.02	3	2.02	2.02
3	9	2.57	11	2.31	2.43
4	11	2.78	6	2.88	2.82
5	2	3.37	8	3.59	3.55
6	0	—	1	4.00	4.00
Total/Avg.	33	2.53	29	2.81	2.66

[a] During establishment year.

Establishment crop

Another aspect of management that was found to be potentially critical was the choice of crop. In general, short-duration crops, which allow two crops per year, or short-statured crops, such as pepper and cowpea (erect type), were most suitable. Creeping crops such as yam (if unstaked) and melon can shade or strangle the tree seedlings. Tree establishment with cassava was satisfactory if both were planted at about the same time. Trees planted into established stands of cassava suffered severe shading. Yam, cassava, maize, and mixtures of these crops were the most commonly planted crops in the alley farms (Table 5).

Accessibility

Both the management and utilization of the trees were affected by the accessibility of the farms from the village, which is mainly a matter of walking distance (although there was one sector of land where the management suffered because of prolonged river flooding). Browse trees on farms located near the village tended to be cut more often for feed.

Tree utilization

Farmers mainly used trees for mulch, fodder, and yam stakes. A survey conducted in 1985 showed that about half of the participating farmers used the trees both for mulch and feed; the other half, for mulch only. Only one farmer used the trees entirely for feed. During the rainy season, foliage was mainly used as mulch; the primary use during the dry season was as fodder. Fodder was tied and hung for the animals. However, no particular attempt was made to prevent animals owned by other members of the household from eating the browse. The requirement for dry-season feed sometimes led to excessive pruning; on some farms, this resulted in tree dieback. In this respect, *Gliricidia* was more vulnerable than *Leucaena*.

Many mulching techniques were observed. Some farmers scattered prunings over the soil; others put prunings in the furrows and split the previous season's ridges over them. Some farmers incorporated prunings into the top of their yam mounds in traditional fashion.

After fodder and mulch, the most common use of the tree was to stake yams. Farmers know staking improves yield and they train the yam vines using any available support (e.g., tree stumps or maize stover, which are left standing in the

Table 5. Crops planted in farmers' alley farms, 1984 and 1985.

Crops	First season		Second season	
	1984[a]	1985	1984	1985
Maize	22 (33.3)[b]	5 (7.9)	17 (25.8)	5 (7.9)
Cassava	3 (4.5)	31 (49.2)	24 (36.4)	26 (41.3)
Yam	14 (21.2)	14 (22.3)	5 (7.6)	10 (15.9)
Pepper	3 (4.5)	2 (3.2)	4 (6.1)	0 (0.0)
Maize–yam	6 (9.1)	2 (3.2)	0 (0.0)	3 (4.8)
Yam–cassava	6 (9.1)	1 (1.6)	4 (6.1)	3 (4.8)
Maize–cassava	12 (18.2)	4 (6.3)	6 (9.1)	3 (4.8)
Fallow	0 (0.0)	4 (6.3)	6 (9.1)	13 (20.6)
Total	66 (100)	63 (100)	66 (100)	63 (100)

[a] Tree-establishment period.
[b] Values in parentheses indicate the percentage of farms.

field for this purpose). However, farmers rarely go outside their farms in search of staking material. Two methods of supporting yam vines with trees were observed: they either cut them to provide stakes in the traditional manner or left the trees uncut and trained the vines up to them. In the latter case, pruning was carried out by stripping the leaves off the main stem by hand.

None of the farmers used the trees for firewood. Frequent pruning does not result in the production of much woody material that could be used for this purpose. Although there is a market for firewood in the villages, it is freely available from fallow land and its value seems to be related to the labour expended in cutting and carrying.

Farmers' perceptions

As part of the process of evaluation, the farmers' perceptions of the new system's benefits were discovered through questionnaires and informal discussions. The beneficial effects of alley farming on soil fertility are only realized in the long term. However, some farmers in their 2nd year claim to have already noticed improved maize yields. Others have commented on the beneficial effect of the trees on the soil, which seemed easier to work. The suppression of weeds such as *Imperata* was another benefit mentioned.

The benefits of the trees for feeding livestock may be realized in the short term: foliage can be cut as fodder even during the 1st year of tree growth. This is believed to contribute greatly to the acceptability of the system to farmers. As previously noted, use of foliage as fodder was widespread. Three farmers had reservations about the effects of the trees on their animals. One farmer believed browse to have been responsible for the accumulation of fat deposits in the abdomen of an animal, which proved fatal. Two other farmers described symptoms that seemed to indicate mimosine toxicity. It was subsequently discovered that one of these farmers had been using only *Leucaena* as feed. Mimosine toxicity is a potential hazard when ruminants are fed a high proportion of *Leucaena*.

These problems notwithstanding, most farmers appreciated the value of high-quality fodder and its beneficial effects on the animals. The animals, too, after an initial period of adaptation, seem to have appreciated the addition of leguminous browse to their diet. One farmer said that his goats had refused to eat the usual maize chaff since acquiring a taste for the browses. Another farmer, who usually fed his goats in the morning, reported that they had begun to knock on his door if browse was not offered on time.

Adoption and diffusion

The spontaneous spread of a technology is the most crucial test of its acceptability to farmers. When the alley farming project began, 66 farmers obtained browse seeds from ILCA; 12 more farmers requested seeds at a later date (Table 6). Of these 78 farmers, 68 planted alley farms. Eight more alley farms were later discovered. These had been established by farmers who had obtained seeds from their neighbours without ILCA's knowledge. This was an encouraging early indication of the potential acceptability of the system. Thus, 76 alley farms were planted in 1984. Farms where tree establishment was so poor that negligible benefit could be expected for either soil or livestock were dropped from the monitoring process. As of July 1985, 68 alley farms were considered viable. By January 1986,

Table 6. Adoption and establishment of alley farms in two pilot project villages.

	Owu Ile	Iwo Ate	Total
Number of farmers who:			
Received seeds from ILCA (March 1984)	38	28	66
Later requested seeds from ILCA	8	4	12
Obtained browse seeds from neighbours	3	5	8
Alley farms established in 1984	49	37	86
Viable in July 1985	38	30	68
Viable in January 1986	31	29	60
Drop-outs (after planting)			
July 1985	4	4	8
January 1986	11	5	16
Farmers obtaining seeds but not planting	7	3	10
Farmers planting in 1985	14	26	40
Farms being monitored, March 1986	45	55	100

60 farms were still being monitored. All but one of the later drop-outs were from Owu Ile.

It is difficult to separate environmental from management factors in explaining the unsuccessful establishment of some farms. In several cases, the trees were planted on land that was due for fallow. This was perhaps a rational, risk-minimizing response to a technology whose costs and benefits were uncertain. Such land would not normally have been planted with crops at all and any labour expended on it was additional to that required on other farms. Returns on such labour would, in any case, have been low and, therefore, such farms naturally attracted little management attention. In other cases, the low level of management would seem to have been due to false expectations about the nature of the project. Some farmers, for instance, had hoped that credit would be forthcoming. For other participants, there were conflicting demands of other occupations.

In 1985, the 2nd year of the project, 40 farmers planted alley farms (Table 6). Among these were two of the farmers who had, in the previous year, made unsuccessful attempts to establish trees in exhausted soils.

The participation of women in the planting of alley farms increased dramatically in 1985. In 1984, only 17% of those planting alley farms were women; in 1985, the proportion was 50%. This higher level of involvement by women followed the posting to the villages of a research associate specifically investigating the question of women's participation in alley farming.

Alley farming has also spread to neighbouring communities. In 1985, farmers from three neighbouring villages approached ILCA for seed to plant alley farms. Another community has initiated contact with ILCA for 1986 planting. These developments, more than anything else, indicated the acceptability of the alley farming system in the zone.

Experimental on-farm trials

The on-farm research described so far has been primarily aimed at the collection of type 2 data. Once the system has been developed, defined, and tested, a more narrowly technical approach may be used to obtain data on production and other coefficients under farm conditions. This is realized through experimental on-farm trials with farmers who have established alley farms in the earlier stages of research (Fig. 2). In this phase, experimental treatments may be superimposed on alley farms originally established under farm conditions.

The methodology for these trials will, in principle, be no different from that of conventional trials managed by the researcher or by the researcher and the farmer (see Collinson 1982; Hildebrand and Poey 1985). These trials use standard research methods, but with emphasis on simplicity and flexibility of design. This is even more important in the case of alley farming because of the complex interactions within the system. This paper does not attempt to present guidelines for conducting such trials. Issues such as number of treatments and replicates, number of farmers, and minimum plot size will differ depending on the objective of the trials and other considerations.

On-farm – on-station relationship

An important feature of the on-farm research strategy outlined in this paper is its ability to increase the relevance of on-station work through the identification of realistic, researchable problems during farmer-managed trials. Feedback from these trials helps define the objectives, design, and methods for on-station work in the light of farmer circumstances, needs, and priorities.

The testing of alley farming technology under farm conditions through developmental on-farm research has given researchers information on the establishment and management of the browse trees under a wide range of environments. Information on their suitability for farmers with varying levels of resources and production objectives has also been obtained. For example, research on the establishment of *Gliricidia* from seed was initiated in response to the problems encountered under farm conditions of establishing the trees using stakes. Seed establishment considerably reduces the bulk of planting material and the cost of transportation and, thus, facilitates diffusion and lowers establishment costs. With the success of this work, the research on stake establishment of *Gliricidia*, which had dominated early on-station research, was discontinued.

There are many examples of on-station trials designed in response to farmers' use of the technology. One experiment assesses the effects of intensive pruning on tree productivity. Another, designed to test the implications of patterns of using trees for feed and mulch, is investigating the long-term effects on soil properties and fertility of carrying off different proportions of foliage or feeding livestock. The splitting of ridges during cultivation, which is a traditional practice of farmers in the area, results in the number of ridges between alleys alternating from three to four in successive years (see Reynolds and Atta-Krah, this volume). A trial is now investigating the effects of maize arrangement within alleys on crop yields; the purpose is to minimize yield loss in three-ridge alleys.

Conclusions

This paper has drawn on the experience of ILCA to illustrate the importance of on-farm research in the evaluation of alley farming. It has considered the role of trials under farm conditions both in the development and testing of technology and in the identification of problems for on-station research. The link between on-farm and on-station research is a dynamic one, and feedback between these two arms of research is essential. Thus, on-station research is concerned both with the definition of the system's potential and with specific problems that emerge from on-farm work.

It has been argued that the nature of alley farming as an enterprise (its systems nature, its flexibility, and its novelty) underlines the need for farmer involvement in the earliest stage of on-farm research. Preliminary on-farm work enables the identification of problems and the adjustment of the technology to farmers' circumstances. In subsequent stages, the growing involvement of farmers in the management and use of the alley farms leads to further development and refinement of the system. The viability and acceptability of the system for farmers is best assessed through community-level pilot projects that involve both research and on-farm testing. This gives farmers maximum control and enables them to exploit an inherently flexible system. Intensive monitoring of farmers' responses to the technology at this stage is essential.

Trials that seek to define the system's technical and production parameters as established under farm conditions can be implemented after this phase. For this purpose, experimental treatments may be superimposed on farms already established by farmers during the pilot project. An attempt to quantify benefits in the early stages, when farmers are still adapting to the technology, would lead to an unrealistic assessment.

The sequence of research outlined in this paper has evolved from ILCA's experience and, therefore, is, in some ways, a rationalization after the fact. It should, therefore not be seen as a rigid prescription. The balance of methods used, as between on-station and on-farm research and between researcher- and farmer-managed trials, will depend on several factors. These include the nature of the technology being developed, the state of existing knowledge, its familiarity to farmers, and its sociocultural and institutional implications.

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Part 5

Country Reports: Semi-arid, Humid, and Subhumid Regions

Alley farming in the semi-arid regions of India

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Abstract — Preliminary studies by the All-India Coordinated Research Project for Dryland Agriculture and Agroforestry indicate that alley farming is suitable for the semi-arid areas of India. Although crop yields grown in adequately spaced alleys are reduced by 25–35%, the use of Leucaena *for firewood and fodder makes the gross economic returns in alley farming almost twice those in sole cropping.* Leucaena *is drought tolerant and, therefore, in areas where rainfall is erratic, the risk of total crop failure is reduced.*

Introduction

This paper summarizes the experimental results presented at the 11th Annual Workshop of the All-India Coordinated Research Project on Dryland Agriculture (AICRPDA) held in Hyderabad, India, in February 1986. After the workshop, delegates from centres with alley farming and other agroforestry trials met to share data and discuss future research strategies. Data from trials conducted at seven of these centres (Table 1) are presented in this paper. Data from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) alley farming trials are not presented here; it is noted, however, where ICRISAT data concur with the findings of the AICRPDA trials.

Site information

Sites cover a range of zones from arid (at Anantapur) to subhumid (at Bangalore and Akola). Most of the sites receive less than 800 mm annual rainfall, with over 85% of rainfall occurring in the cropping season. For 2 months, precipitation exceeds potential evapotranspiration, meeting the semi-arid region definition (Virmani et al. 1980). Because rainfall varies considerably from year to year throughout the dry zone of India, crop-production data presented in this paper are accompanied by pertinent seasonal rainfall data. All sites have annual mean temperatures exceeding 18°C, with mean highs of over 40°C in April–June and lows of below 15°C in December–January (Virmani et al. 1980).

Table 1. Rainfall (mm) and soil data of AICRPDA stations with alley cropping trials.

Location	No. of months P > PE[a]	Average rainfall: Annual	Average rainfall: Crop season	Soil type
Anantapur	0	560	495	Shallow Alfisol
Kovilpatti	2	730	474	Typic Chromostert
Hyderabad	2	770	545	Shallow Alfisol
Solapur	2	772	541	Medium Vertisol
Rajkot	3	625	475	Medium Vertisol
Bangalore	3	888	613	Oxic Haplustalf
Akola	4	878		Medium Vertisol

Source: TNAU (1983), UAS (1983), MPAU (1984), PKV (1985), APAU (1986).
[a] P, precipitation; PE, potential evapotranspiration.

No detailed soil data are presented, but broad soil types are listed in Table 1. The soils in the trials are either the red type (Alfisols) or "black soils" (Entisols or, more commonly, Vertisols). Red soils are characterized by low water-holding capacity, near neutral or slightly basic pH, low nitrogen and available phosphorus status, and a tendency to crust after showers. They are invariably cropped during the rainy season (*kharif*). The black soils, with low infiltration rates but good water storage, are cropped in the postrainy season (*rabi*), when stored soil water is used for crop growth. They have excellent cation exchange capacity but often lack available phosphorus and organic matter.

The authors faced several constraints in preparing this report. Firstly, there was a lack of research uniformity. Until the last 2 years, there was little attempt made to coordinate trials. Experimental designs, alley spacings, crops, and treatments all varied considerably between sites (Table 2). Secondly, few of the trials had sufficient sole crop checks. There was insufficient emphasis on statistical analysis — most of the data are taken from annual station reports, wherein the means are usually listed in tabular form with little or no statistical analysis. Finally, all trials used only *Leucaena leucocephala* as the hedgerow species. Readers should therefore overlook the paucity of statistical analysis and examine trends in the data across sites. Differences in selected crops between sites reflect the predominant crops grown in the area. Regarding the exclusive use of *Leucaena*, it must be pointed out that *Leucaena* has proven to be quite adapted, once established, to even extreme drought conditions, i.e., past the first rainy season. It appears likely that *Leucaena* will remain the preferred choice by researchers and eventually by farmers in agroforestry systems in the dryland regions of India.

Alley farming characteristics

When asked by field researchers of the Central Research Institute for Dryland Agriculture (CRIDA) what the biggest constraint to farming was, residents of the Telangana region, Andhra Pradesh, answered, "lack of water." They identified the second largest constraint as lack of fodder (D. Hocking and D.G. Rao, unpublished

Table 2. Experimental designs and crops in alley cropping trials.

Location	Design[a]	Treatments	Crops
Akola	RCB	3 crops, ± mulch, 3- and 6-m alleys	Sunflower (*Helianthus annuus*), sorghum (*Sorghum bicolour*), pigeon pea (*Cajanus cajan*)
Anantapur	RCB	3 crops, ± mulch, 2- and 4-m alleys	Groundnut (*Arachis hypogea*), pigeon pea, millet (*Pennisetum typhoides*)
Bangalore	RCB	2 alley spp., 2 harvest regimes	Finger millet (*Eleusine coracana*)
Hyderabad	RCB	4 crops, 3-, 6-, 7-, and 8-m alleys, ± mulch	Castor (*Ricinus communis*), millet, sorghum, pigeon pea
Kovilpatti	Split plot	3 crops, 2 cutting heights, 3- and 6-m alleys	Sorghum, millet, pigeon pea
Rajkot	RCB	3 crops, 2 alley configurations	Urd bean (*Phaseolus mungo*), mung bean (*Vigna radiata*), groundnut
Solapur	RCB	± mulch, 3 N levels	Sorghum

Source: TNAU (1983), UAS (1983), MPAU (1984), PKV (1985), APAU (1986).
[a] RCB, randomized complete block.

data). Farmers in the Indian drylands are often forced to sell bullock teams in the dry season, sometimes at just 10% of their true worth, because of fodder scarcity. In many cases, it takes years to recover from this setback.

Lack of fodder in the dry season is a continuing problem and ranked higher in impact on the farmer in the CRIDA survey than fuelwood scarcity. In fact, fuelwood scarcity was ranked rather low by farmers, behind declining soil fertility and soil erosion.

The Indian Grasslands and Fodder Research Institute (IGFRI), in Jhansi, India, has demonstrated that increased fodder production is feasible; however, extension of these technologies to farmers' fields has proven difficult. Alley farming may be an effective way to extend fodder cultivation to the farm. It has the potential of allowing the farmer to produce fodder without seriously disrupting existing farm practices. Additional benefits such as providing green leaf for mulch in the rainy season, small-diameter firewood, the improvement of soil fertility, and conservation have all been demonstrated in AICRPDA trials.

The alley cropping model of the International Institute of Tropical Agriculture (IITA) (see Kang et al., this volume) emphasizes the end use of lopped material as mulch. Secondary benefits include biological nitrogen fixation, soil conservation, and the other uses of lopped material (e.g., browse, staking material, and firewood). The major goal of alley cropping in the IITA model is to stabilize shifting cultivation areas.

In the semi-arid regions of India, the primary benefit of alley farming is fodder supply. Alley farming is viewed as a more or less permanent fixture of farms, with alleys spaced at wide enough intervals to lessen their negative impact on crops. Even in the rainy season, when green fodder is in good supply, farmers may feed livestock the high-quality browse from the hedgerows. Alternatively, green manuring with the loppings may prove to be attractive in some areas. Either way, this continual lopping obviates allowing hedgerows to "grow freely to cover the land."

Cutting height of hedgerows

Based on numerous fodder-production schemes with *Leucaena* in India, a cutting height of 50–75 cm was employed for most trials. In Bangalore, Krishnamurthy and Munegowda (1982) reported that 40- to 50-day harvest intervals and cutting heights of 75 and 150 cm yielded as much as 50% more foliage than a 15 cm cutting height. Lower harvest frequency narrowed the yield differences between the 15 and 75 cm cutting heights; stumps cut at 150 cm produced more foliage at longer intervals.

More work needs to be done on cutting height in alley farming for the semi-arid tropics, particularly very low heights (10–20 cm), which could be used to reduce competitive effects of hedgerows on crops. Also, it is not known whether there are interactions between yield of the various crops and cutting height, although preliminary data from the Kovilpatti station (TNAU 1983) suggest such a relationship.

Alley width

Alley spacings from 2.0 to 7.8 m are represented in the trials; it is useful to compare the performance of crops within the various alley spacings (Table 3). At 2 years, the ratio of yields for alley cropped versus sole-cropped pearl millet decreased systematically with decreasing alley width. This trend appears to be more or less independent of rainfall, although the rains at Kovilpatti proved adequate to overcome the competitive effects of the young hedgerows, even at 3-m spacing. It will be worthwhile to monitor the effect of alley spacings with time to see if this trend continues.

There is evidence that alley widths between 3 and 4 m are severely competitive with crops. A 5-year-old trial at CRIDA (Hyderabad) allows yearly comparison of competitive effects between *Leucaena* hedges and crops grown in the alleys (Table 4). In the 1st year, pearl millet grown in 3.6 m wide alleys produced 83% of the grain yield of sole pearl millet. By the 5th year, however, this ratio decreased to just 26%, a nearly linear trend. Yields in wider alleys (7.8 m) also decreased from a high of 93% of sole crop in the 2nd year to 60–65% in years 3–5. In 2-year-old alley farming trials at ICRISAT, yields of sorghum dropped about 45% when planted with a pigeon pea intercrop between 4.65 m *Leucaena* alleys (M.R. Rao, personal communication).

Table 3. Effect of alley spacing on millet yield (hedgerow age, 2 years).

Location	Alley spacing (m)	Seasonal rainfall (mm)	Grain yield (t/ha) Sole crop	Alley crop	Ratio (%)
Anantapur	2	326	0.24	0.10	40
Kovilpatti	3	396	0.73	0.59	81
Hyderabad	3.6	190	1.31	0.89	68
Anantapur	4	326	0.24	0.18	75
Kovilpatti	6	396	0.73	0.65	89
Hyderabad	7.8	190	1.31	1.22	93

Source: TNAU (1983); APAU (1986); G.R. Korwar and D. Hocking (unpublished).

Table 4. Effect of hedgerow age on pearl millet yield, Hyderabad, India.

Hedgerow age (years)	Alley width (m)	Seasonal rainfall (mm)	Grain yield (t/ha) Alley	Sole	Alley/sole ratio (%)
1	3.6	549	1.22	1.47	83
	7.8		1.24		84
2	3.6	190	0.89	1.31	68
	7.8		1.22		93
3	3.6	717	1.35	2.60	52
	7.8		1.54		59
4	3.6	209	0.47	1.54	31
	7.8		0.97		63
5	3.6	145	0.53	2.05	26
	7.8		1.36		66

Source: G.R. Korwar and D. Hocking (unpublished data).

The apparent stability of the widely spaced alley systems after the 2nd year is promising. However, a few more years' data will be necessary before it can be concluded that competition effects have truly stabilized. This general trend of increased hedgerow competitiveness over time was noted in all trials; some crops were more affected by competition from *Leucaena* hedgerows than were others.

It is clear from these examples that selection of alley width is much more important in the semi-arid tropics than in the subhumid and humid tropics. Even greater widths (e.g., 15–20 m) must be examined for their effect on crop production. It is expected that farmers may not tolerate large decreases in grain and stover yield from alley cropping despite the offsetting value of the loppings.

Mulching

A primary purpose of alley farming in the humid tropics is the green manure from loppings. Data from various studies in the semi-arid tropics with green manure are somewhat contradictory. In a 3-year-old trial at Solapur, addition of

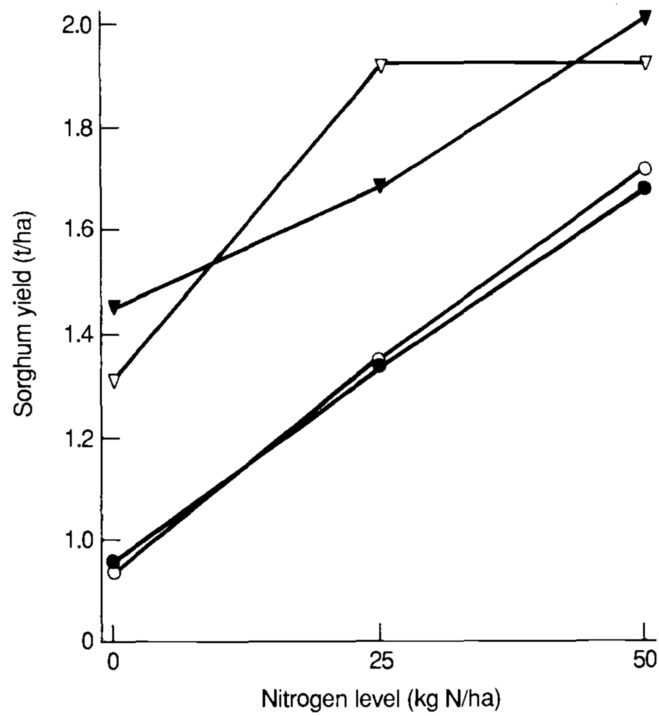

Fig. 1. Effect of *Leucaena* mulching, nitrogen level, and alley cropping on sorghum yield over a 3-year period: ▿, sole crop + mulch; ▾, alley crop + mulch; ○, sole crop (no mulch); ●, alley crop (no mulch) (source: MPAU 1983).

mulch in either alley cropped or sole-cropped sorghum increased yield significantly over plots that were unmulched. Other benefits from green manuring were increased average N content of the soil, increased N and P uptake by the pearl millet crop, and improved efficiency of moisture use for grain production (MPAU 1984). Somewhat surprisingly, no yield differences occurred between the alley-cropped and sole-cropped sorghum with either the mulched or unmulched treatments (Fig. 1).

Data from other years at Solapur showed similar trends, but less clearly. In general, a 15–30% yield increase over the control was noted in years 1 and 2 with *Leucaena* mulching.

Other sites gave contradictory results. In a trial with finger millet at Bangalore, *Leucaena* prunings decreased both grain and straw yield in mulched plots in two successive years (Table 5). Although these yield decreases are probably not significant, the fact that yield did not increase with mulching is noteworthy.

In an ongoing study, G.R. Korwar and D. Hocking (unpublished data) examined four crops in mulched and unmulched alleys of 3.6 and 7.8 m. *Leucaena* prunings from mulched alleys were applied to the crop during the cropping season and removed for fodder during the off-season. During the 1984 cropping season (year 4 of the study), the 7.8-m alley showed less competitive effects than the 3.6-m alley (Table 6).

Table 5. Effect of mulching on yield of alley-cropped finger millet (t/ha) in Bangalore, India, 1982 and 1983.

Treatment	1982 Grain	1982 Straw	1983 Grain	1983 Straw
Alley cropped + mulch	1.80	1.28	2.21	3.14
No mulch	2.15	1.41	2.50	2.51
Sole crop	2.47	1.75	3.97	5.19
Seasonal rainfall (mm)	440		429	

Note: Alleys, 6 m; cutting height, 1.5 m. Yields are on net area basis and do not include the area occupied by the alleys.
Source: UAS (1983).

Table 6. Effect of mulching on crop yield in Hyderabad, India, 1984.

Crop and treatment	Grain yield (t/ha)	*Leucaena*[a] leaf yield (dry) (t/ha)	Seasonal rainfall (mm)
Castor			
Sole crop	0.64	—	329
Alley crop, mulched	0.39	0.75	
Alley crop, no mulch	0.39	1.93[b]	
Pearl millet			
Sole crop	1.54	—	209
Alley crop, mulched	0.96	0.80	
Alley crop, no mulch	0.97	1.85[b]	
Sorghum			
Sole crop	1.08	—	209
Alley crop, mulched	0.71	0.64	
Alley crop, no mulch	0.67	1.02[b]	
Pigeon pea			
Sole crop	0.58	—	329
Alley crop, mulched	0.34	0.81	
Alley crop, no mulch	0.29	2.09[b]	

Note: Alley width, 7.8 m.
Source: G.R. Korwar and D. Hocking (unpublished).
[a] *Leucaena* reported in mulched treatments is that harvested in the off-season.
[b] Hedgerows not pruned.

Besides the extreme differences in response to alley versus sole cropping for the various crop species, the data also show a lack of response to mulching. For no crop did mulched alleys demonstrate a clear, significant yield increase over unmulched alleys, despite the addition of an average of 4 t/ha of green *Leucaena* loppings (i.e., about 40 kg N). Data from the 5th year of the trial showed a slight improvement in the mulched sorghum plots; however, the difference between the mulched treatment and sole sorghum is not significant.

This variability in response to green manuring in the AICRPDA trials prevents any definitive recommendation at this stage. For now, mulching will remain part of the trials and the few sites that have not had a mulching treatment will have one next year.

Green fodder of the quality of *Leucaena* is a valuable commodity in both rural and urban India. In view of this, it is unlikely that the use of loppings from *Leucaena* hedgerows as green manure can be extended to the farm unless clear and consistent advantages in crop yield are the result.

Land equivalent ratios

Land equivalent ratios (LERs) are available for only two sites: Anantapur and Akola (Table 7). All the other sites did not include a sole *Leucaena* plot for yield comparison. Five crops are compared with four alley widths. The data are rather recent (Akola, 1 year; Anantapur, 2 years) and will, therefore, need verification in subsequent years. In all crops except pigeon pea, LERs are greater than 1. Alley farming trials using a sorghum – pigeon pea intercrop between *Leucaena* hedges at ICRISAT showed no advantage over sole cropping in 2-year-old alleys (M.R. Rao, personal communication). There appears to be no consistent pattern to LERs in the few trials where they are able to be calculated, although such trends may emerge as the trials progress.

Table 7. Land equivalent ratios (LERs) in alley cropping systems.

Crop	Location	Seasonal rainfall (mm)	Alley data: Width (m)	Alley data: Age (years)	LER
Millet	Anantapur	326	2	2	1.07
			4	2	1.22
Sorghum	Akola	671	3	1	1.14
			6	1	1.00
Groundnut	Anantapur	326	2	2	1.12
			4	2	1.03
Pigeon pea	Anantapur	326	2	2	0.83
			4	2	0.95
Sunflower	Akola	671	3	1	1.08
			6	1	1.17

Source: PKV (1985), APAU (1986).

Alternate management methods

One clear advantage of alley farming over sole cropping is its flexibility of management. One such option at CRIDA (Hyderabad) involves the establishment of *Leucaena* alleys at 5-m intervals along the contour on a gently sloping portion of the Gunegal farm. Hedgerows were lopped as usual, except that a *Leucaena* plant was allowed to grow every 2 m along the hedgerow. The rationale for this practice is in the profusion of lumberyards in the Hyderabad area, where poles of eucalyptus (*Eucalyptus camaldulensis*) and casuarina (*Casuarina equisitifolia*) sell for INR 60 for a 10 cm × 6 m stem (in December 1988, 15 Indian rupees [INR] = 1 United States dollar [USD]).

Table 8 shows the effect of this arrangement on crop growth. When compared with sole crops, the reduction in alley crop yield was more severe in 1985 than in 1984 because of the lower, more poorly distributed rainfall. The hedgerows, however, yielded more green fodder in 1985 (4.01 t/ha) than in 1984 (2.74 t/ha).

Yield reduction of grain crops in 1984 was about normal compared with other alley crop experiments in CRIDA's nearby Hayatnagar farm. Yield reduction during 1985 was the worst at all sites. It is likely that the arboreal *Leucaena* severely affected crop growth in 1985 through competition for moisture. Therefore, the data suggest that allowing *Leucaena* to grow unmanaged in cropped fields is unadvisable, particularly in areas with a high probability of monsoon failure and soils with low water-holding capacity.

Table 8. Grain yields of crops grown in 5-m alleys with arboreal *Leucaena* every 2 m.

Crop	Year[a]	Grain yield (t/ha) Sole	Grain yield (t/ha) Alleys	Yield reduction (%)
Millet	1984	1.92	1.35	30
	1985	3.68	0.77	79
Sorghum	1984	1.98	1.34	32
	1985	3.19	0.84	74
Mung bean	1984	0.56	0.43	24
	1985	0.92	0.27	71
Cowpea	1984	0.84	0.45	46
	1985	1.46	0.30	80
Castor	1984	0.83	0.47	44
	1985	0.72	0.06	92
Groundnut	1984	1.80	0.88	51
	1985	0	0	—

Source: R.P. Singh (unpublished).
[a] Cropping season rainfall: 1984, 431 mm; 1985, 375 mm.

Leucaena poles are a possibly attractive source of income to a small farmer and the negative effects of crop competition can be overcome if the tree canopies are lopped or, better still, pollarded (cut 2–4 m above ground). In a related experiment at CRIDA (Table 9), *Leucaena* trees were established at 2-m intervals along the contours with 2-m spacing within rows. When the trees were 4 years old and about 8 m tall, four treatments — unlopped, lightly lopped (33% canopy removal), heavily lopped (66% canopy removal), and pollarded at 2 m — were established and sorghum was grown underneath the trees.

Sorghum grain yield was seriously affected by unlopped and lopped treatments, with only 5% of sorghum yield in the heavily lopped treatments and no grain yield under unpruned trees. Evidently, the unpruned foliage was a strong sink for soil moisture, to the detriment of the crops. Pollarded plots had better crop production: 45% of grain and 69% of stover yields compared with sole sorghum plots. Pollarded plots also produced nearly twice the *Leucaena* fodder than lopped treatments. In terms of total biomass, sorghum under pollarded *Leucaena* was 29% more productive as sorghum alone and 47% more productive than *Leucaena* alone. The LER of the pollarded treatment was 1.35.

Such severe pruning of *Leucaena* to favour crop growth is potentially useful in hedgerow-type alley cropping situations. Keeping the hedge cut back to 10 cm in the cropping season through frequent harvests is a management option that would be attractive to farmers who routinely include two weedings as part of their crop management. *Leucaena* harvest expenses could be incorporated into these weeding operations. With this modification of low cutting height, overall fodder harvest will no doubt decrease; however, there will be a concomitant increase in crop yield. AICRPDA alley cropping trials will incorporate a 10-cm cutting height in 1986.

Table 9. Yield components (t/ha) from managed arboreal *Leucaena* and sorghum agroforestry system, Hyderabad, India.

Management method	*Leucaena* (dry)[a]			Sorghum[b]		Total biomass	LER[c]
	F	W	I	G	S		
Sole *Leucaena*[d]							
Unlopped	—	—	4.5	—	—	4.5	—
Lightly lopped	1.2	0.3	3.5	—	—	5.0	—
Heavily lopped	1.4	0.3	3.1	—	—	4.7	—
Pollarded	2.3	5.2	1.9	—	—	9.3	—
Sole sorghum	—	—	—	2.9	5.7	8.5	—
Leucaena + sorghum							
Unlopped	—	—	3.6	0.0	0.8	4.3	0.9
Lightly lopped	1.5	0.3	2.6	0.1	1.6	6.1	1.1
Heavily lopped	1.4	0.3	2.4	0.3	1.7	6.0	1.1
Pollarded	1.2	3.8	1.8	1.3	3.9	12.1	1.4

Source: D.G. Rao and D. Hocking (unpublished).
[a] F, fodder; W, wood; I, standing wood increments.
[b] G, grain; S, stover.
[c] Land equivalent ratio.
[d] *Leucaena* was planted in a 2 m × 8 m configuration. Trees, 4 years old; seasonal rainfall, 144 mm.

Crop complementarity

Tables 4–8 show that crop yield is affected by the presence of *Leucaena* hedgerows. This effect may be lessened by more frequent prunings of the hedgerow, lower cutting heights of the hedgerow, and larger hedgerow spacings.

The data also show that the choice of the crop is important in the success of alley farming in semi-arid regions. Many crops are simply not compatible with *Leucaena* in alley farming systems; others compete successfully with hedgerows for soil moisture and nutrients.

Of all the crops tested in the AICRPDA trials, pearl millet and sorghum were best, particularly when alley widths were sufficiently wide for good crop establishment. For sorghum, alley/sole crop ratios ranged from 52 to 98% (mean, 77%) in the wider alleys for 8 of the 9 plot-years reported. Only one centre (Hyderabad) reported a lower value: 40% for the dry year of 1985.

Pearl millet, although not as widely tested as sorghum, showed similar results. Alley/sole crop ratios ranged from 59 to 93% in wide alleys (mean, 76%; n = 7 plot-years). No centre reported ratios less than 59%, suggesting that pearl millet has slightly greater stability than sorghum in alley cropping systems.

The success of pearl millet and sorghum in alley farming systems is probably due to their shallow (< 60 cm), aggressive rooting systems. These systems compete favourably with the *Leucaena* hedgerows while allowing *Leucaena* to feed off soil water that has percolated past the cereal root zone. This theory is being tested with soil moisture studies at CRIDA and ICRISAT.

Oilseed crops including castor, sunflower, safflower, and groundnut appear intermediate in tolerance to alley cropping. Alley/sole crop ratios of 61–88% were reported for castor at the Hyderabad centre; however, these values do not include yields of the current dry year of 1985. Castor was severely affected by drought and *Leucaena* alleys in the 1985 cropping season at Hyderabad. Similar observations were noted in nearby ICRISAT alley cropping trials, where sunflower was also badly affected in 1985 (M.R. Rao, personal communication).

Pigeon pea fared worst of all the crops tested, with outright crop failures reported at several centres. This is probably due to the deep rooting of pigeon pea, which apparently is not able to aggressively dominate the lateral roots of established *Leucaena* hedgerows early enough to successfully compete for soil moisture.

Pulse crops such as cowpea, urd bean, and mung bean were tested in the various trials. The lack of data on these crops do not allow any kind of definite recommendation. More work needs to be done in this area.

Benefits of alley farming

Alley farming is already being extended to farmers in several model watersheds in the India-wide program on small watershed development begun in 1982 by the Indian Council of Agriculture Research. Widespread adoption of alley farming, however, will depend on its ability to stabilize production and, in the final analysis, make money.

Species diversification

One strong argument for alley farming is its ability to produce usable material, even in years of severe drought. Rajkot in 1985 is an example of the ability of alley farming to offset the impact of crop failure in areas of unassured rainfall. Rainfall there was 30% less than normal, leading to the total failure of grain production for three legume crops. In sole crop plots, production was limited to 0.5–1.7 t/ha of green stover usable as fodder. In alley farmed plots, however, *Leucaena* hedgerows produced over 5 t/ha of green fodder (Table 10).

This ability to produce even in bad years was also noted at the Anantapur centre, where cropping season rainfall was only 144 mm in 1984 (normal, 495 mm). All crops (groundnut, pigeon pea, sorghum) failed; even stover production was severely affected. However, the *Leucaena* hedgerows produced 2 t/ha of dry leaf material (B. Sreenivas, personal communication).

When properly planned, *Leucaena* hedgerows can remove part of the risk facing the small farmer in India. The farmer must feed the livestock during both the dry season and cropping seasons when the rains fail. With *Leucaena*, this can be done without severe negative impact on crop production.

Economic benefits

Before the economic benefits of a *Leucaena*-based alley farming system can be defined, an accurate estimate of the market value of *Leucaena* by-products must be derived. In India, no established market exists for *Leucaena* wood or fodder, although there are well-defined markets for similar products: i.e., eucalyptus and casuarina poles, *Acacia nilotica* firewood, and sunn hemp (*Crotolaria juncea*), groundnut tops, and other fodders. It is likely, therefore, that a market for *Leucaena* will develop in the future. Prices of these commodities can provide the basis for pegging the market value of *Leucaena* products for their respective end uses — primarily firewood and fodder.

Table 10. Risk reduction in poor rainfall years through alley cropping at Rajkot Experimental Station.

Treatment	*Leucaena* fodder (wet) (t/ha)	Crop yield (t/ha) Grain	Stover
Sole crops			
Leucaena[a]	5.75	—	—
Groundnut	—	0	1.67
Mung bean	—	0	0.68
Urd bean	—	0	0.47
Alley crops			
Groundnut	5.24	0	1.26
Mung bean	5.56	0	0.25
Urd bean	6.03	0	0.22

Note: Rainfall, 177 mm (120 mm in cropping season); average rainfall, 625 mm.
[a] Rows of 1.5 m.

Table 11. Economic analysis of alley cropping.

Crop	Crop yield (t/ha)		*Leucaena* yield (t/ha)					Cash returns (INR x 10^3/ha)[a]		
			Fodder		Fuel					
	Grain	Stover	Crop season	Off-season	Stems	Stumps	Seeds	Crop	*Leucaena*	Total
					Alley cropped					
Sorghum	1.09	3.9	7.2	3.1	6.5	3.3	0.4	2.34–5.66	7.48	9.82–13.14
Pigeon pea	0.13	0.3	10.7	5.2	10.7	0.3	0.9	1.72	10.36	12.08
					Sole cropped					
Sorghum	1.55	5.1	0	0	0	0	0	3.25–7.20	0	3.25–7.20
Pigeon pea	0.43	0.4	0	0	0	0	0	1.80	0	1.80
SE	0.04	0.4	0.8	0.9	0.9	0.2	0.03			

Note: Seasonal rainfall, 430 mm.
Source: TNAU (1984).
[a] In December 1988, 15 Indian rupees (INR) = 1 United States dollar (USD).

Market values for *Leucaena* were derived from a CRIDA study of commodity prices in Andhra Pradesh (see Appendix). The price of *Leucaena* fodder during the crop season (INR 250/t) was based on the prices of green grass (INR 100/t) and green sunn hemp (INR 300/t). During the off-season, fresh *Leucaena* would, naturally, be more valuable (INR 500/t). The value of the dry *Leucaena* leaf meal would be only slightly less than groundnut cake during the dry season (INR 2 000/t) and, during the cropping season, nearly equal the price of dried sunn hemp (INR 1 000/t). In light of the high quality of *Leucaena* fodder, these prices are considered conservative.

The value of wood from *Leucaena* was placed at INR 300/t for branches and INR 400 for stumps of plants in alley crops, based on market prices of similar wood products. Seeds for propagation now sell for INR 20–50/kg, depending on source; however, a value of INR 2/kg was chosen as a predicted price for *Leucaena* used commercially as a source of gums and oils. No market yet exists for this use, but research continues at a number of centres.

Data for the production of alley farming was derived from reports of the Kovilpatti Station (Table 11). The alley farming trial at this station was run for 3 years and then harvested. *Leucaena* stumps in the alleys were cut, weighed, and prorated over the 3-year period. The range of prices was substituted for the production figures of sorghum and pigeon pea grain and stover, and for *Leucaena* fodder, wood, and seeds.

Gross cash returns are higher in all cases for alley-farmed systems. Alley-farmed sorghum yielded nearly twice the income of sole sorghum. The alley-farmed pigeon pea system yielded almost seven times the income of sole pigeon pea; this was due to the value of *Leucaena* by-products. Most of *Leucaena*'s value is derived from its sale as a fodder, which appears to be of greater economic benefit than its application to the crops as a green mulch.

Admittedly, these numbers are based on computed values of *Leucaena*; nonetheless, they are realistic, especially when one considers how fast *Leucaena* is being accepted by Indian farmers. Costs, which presumably will be higher in the *Leucaena* systems, however, need to be incorporated into the model. This will be done in the future using ICRAF's computer program (Hoekstra 1984).

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Appendix. Prices (INR/kg)[a] of agricultural products in Andhra Pradesh, 1985.

Sorghum

Grain: crop season, 1.20–2.25; off-season, 1.60–2.75
Stover: crop season, 0.25–0.50; off-season, 0.40–0.87

Pigeon pea

Grain: 4.00
Stover: 1.60

Fodders

Grass (wet): 0.10	Groundnut cake: 2.50
Sunn hemp: 1.25	Cottonseed cake: 1.50
Rice bran: 2.30	Groundnut tops (dry): 1.37
Wheat bran: 1.60	Pigeon pea husks and brokens: 1.80

Firewood

Farmgate, preferred species: 0.40
Prosopis: 0.37–0.43

***Leucaena* coproducts**[b]

Fodder: crop season, 0.25 (wet), 1.00 (dry);
off-season, 0.50 (wet), 2.00 (dry)
Fuel: branches, 0.30; stumps, 0.40
Seeds: propagation, 20–50; commercial, 2.00

Source: D. Hocking and K.P.C. Rao (unpublished data).

[a] In December 1988, 15 Indian rupees (INR) = 1 United States dollar (USD).

[b] Computed values.

Alley cropping under semi-arid conditions in Kenya

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Abstract — The Dryland Agroforestry Research Project was designed to test several agroforestry interventions aimed at reversing the constraints that have recently appeared in the semi-arid lands of Kenya as a result of population pressure. These constraints were discovered following the application of the International Council for Research in Agroforestry's diagnosis and design methodology to a typically semi-arid area in eastern Kenya. One of the intervention technologies designed to counteract these constraints is alley cropping. This paper describes on-station and on-farm alley cropping experiments. The trials are still in their initial stages and it is too early to say whether alley cropping will be successful in the semi-arid areas of Kenya.

Introduction

In Kenya, rapid population growth (about 3.8–4.0% annually), limited arable land, and a shortage of employment opportunities in the industrial and service sectors have led to an increase in the number of smallholders farming and ranching on Kenya's marginal, semi-arid lands. This trend is expected to continue into the 21st century.

Increased settlement and exploitation of these semi-arid lands provide a basis for the livelihood of small-scale farmers; however, the results are mixed. The soils, especially those on the steeper slopes, are subject to serious erosion. Much of the rangeland has been overgrazed and the ground cover in some areas is badly degraded. Also, rainfall in the semi-arid zone is low (600–800 mm) and subject to considerable variability.

These factors, combined with traditional methods of farming and ranching, have led to a low standard of living for many rural inhabitants in these areas. When rainfall is deficient, the Government of Kenya has diverted scarce treasury funds to famine relief for those most seriously affected. Moreover, the resulting depletion of the natural resources (forestry included) does not augur well for future generations who are expected to live on these marginal lands.

A preinvestment inventory study of the marginal semi-arid lands in Kenya conducted during 1977 and 1978 found that major investments in soil conservation, farm-production technology, and infrastructure are needed to reverse the rapid decline in the quality of life and the condition of the physical environment in the semi-arid lands.

Several institutions are now geared to fulfill this goal. The Katumani Research Station, in collaboration with the Food and Agriculture Organization of the United Nations (FAO), the Kenya Agricultural Research Institute (KARI), and the United States Agency for International Development (USAID) are trying to determine appropriate agricultural systems for the semi-arid areas; the European Development Fund is also sponsoring an integrated development program in Machakos District. Most research so far has focused on purely agricultural or livestock systems, although the potential role of trees has been clearly recognized by each of these institutions. In this context, an agroforestry research project becomes an important and appropriate contribution to the overall development of the semi-arid lands. Machakos District was selected for a 4-year pilot project on dryland agroforestry financed by the International Development Research Centre (IDRC). The project began in September 1983.

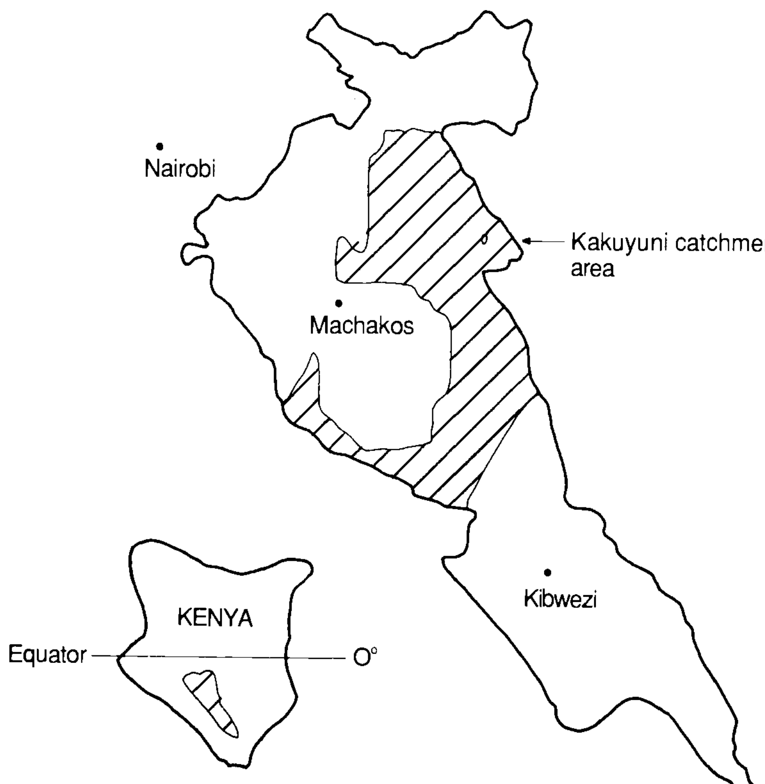

Fig. 1. Location of the research site and recommendation domain in Machakos District, Kenya.

The target area

The Kakuyuni catchment area, located in Machakos District on the Yatta Plateau, falls within agroclimatic zone 5 (Sombroek and Siderius 1982), a semi-arid region of about 1 million ha (69% of the district's land area), and supports 465 000 people (43% of the district's population, 1979 census). Kakuyuni is considered to be representative of the more densely populated areas of zone 5, where farmers are more dependent on agriculture than grazing (Fig. 1).

Terrain and soils

The catchment area is about 1 200 m above sea level and the terrain is gently to moderately sloping. Soils in the catchment area are well drained, shallow to deep, dark red, friable clay, and rocky in many places (Nito Rhodic Ferralsols and Nito Chromic Cambisols, including lithic and bouldery phases). In some depressions, a poorly drained, dark greyish-brown to black, firm, slightly calcareous, cracking clay can be found with a saline and sodic deeper subsoil (Pellic Vertisols) and a partly saline–sodic phase (with eutric or vertic Gleysols) (Sombroek and Siderius 1982).

The Ferralsol–Cambisol soil association, including rocky phases, suffers from low inherent fertility once the organic matter content is diminished by arable cropping; it also has a low capacity to retain added nutrients. Maintaining or raising the organic matter content is thus of particular importance.

The dark Vertisols found in poorly drained depressions are difficult to cultivate as they are sticky and stiff when wet and hard when dry. The poor drainage is also a problem for most crops other than rice.

Climate

In the Kakuyuni area, optimal water requirements (E_t), on average, are only met in November. The lower limit of normal plant water needs (0.4 E_o) is exceeded by precipitation only in April, November, and December (Fig. 2). These unfavourable climatic conditions are further aggravated by the seasonal and yearly variation in rainfall (Table 1). The names "long rains" and "short rains" (Table 1A) are somewhat misleading in the survey area, as the rainy period of October–December (short rains) is longer than the long rains from March to May. Furthermore, the amount and probability of rainfall from October to December is higher (Table 1B). Therefore, the October–December rainy season poses less risk to cropping activities.

Vegetation

The dominant tree–shrub vegetation in the area is mainly *Combretum molle*, *Acacia abyssinica*, *Balanites aegyptiaca*, and *Terminalia brownii*. These species are mainly found on red clay soils; *Acacia drepanolobium* is common on black clay soils.

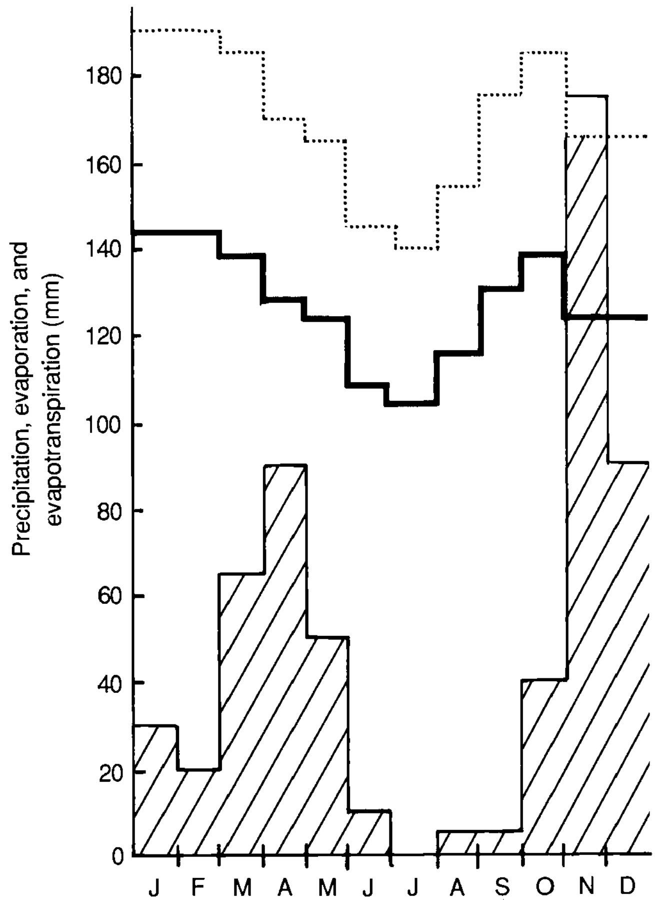

Fig. 2. Mean annual precipitation (shaded area), potential evaporation (solid line), and potential evapotranspiration (dashed line) throughout the year in the Kakuyuni area (Woodhead 1968; Kenya Meteorological Department).

Dryland agroforestry research project

The diagnosis and design methodology of the International Council for Research in Agroforestry (ICRAF) was used to identify research needs for the target area. The diagnostic and prediagnostic data collected from the Kakuyuni area indicated the following characteristics:

- low productivity of crops as a result of low soil fertility (low organic matter and nitrogen levels);
- high rate of soil erosion and runoff;

Table 1. Rainfall on the project site.

(A) Projected onset and cessation.

Description	**Onset**	**Cessation**	**Duration (days)**
Long rains	12–16 Mar.	1–5 May	50
Short rains	18–22 Oct.	22–26 Dec.	60

(B) Seasonal probability (%).

Period	**>100 mm**	**>150 mm**	**>200 mm**	**>250 mm**	**>300 mm**
Mar.–May[a]	75	54	38	23	15
Oct.–Dec.[b]	96	90	74	58	39

Source: Jaetzolf (1979)
[a] Mean March to May rainfall, 195 mm.
[b] Mean October to December rainfall, 305 mm.

- shortage of animal fodder, especially during the dry season;
- shortage of fuelwood and building poles; and
- shortage of cash (no cash crops).

Project objectives

The project aims to develop agroforestry technologies for the semi-arid areas of Kenya and other East African countries, with a view to improving the quality of life of the inhabitants. Following the identification of constraints, the following project objectives were specified:

- to examine the possibilities of maintaining or increasing productivity by establishing alley cropping;
- to examine the possibilities of improving the quality, quantity, and seasonal distribution of forage on the farm by planting fodder tree or shrub species in the grazing areas and by developing cut-and-carry forage systems;
- to examine the possibilities of reducing the labour requirements of the free-grazing system and fuelwood collection by establishing live fences around grazing land and planting fuelwood species on the farm; and
- to examine the possibilities of increasing the cash income of the farmers by the introduction of fruit trees.

Most of the project objectives have been initiated. A summary of the alley cropping trials is presented here. For detailed discussions, descriptions of experimental layout, and data analysis, see Arap-Sang et al. (1985) and Arap-Sang and Hoekstra (1986a, b, c).

Leaf-manuring trials

As a forerunner to alley cropping trials, a small trial was initiated to screen the effect of different tree leaves and their rates of application on plant growth. The leaves were incorporated into the soil. Beginning in October 1983 at Katumani National Dryland Farming Station, Maruba Farm, the trial used four replications: *Cassia siamea*, 1 and 2 kg/m^2 (fresh weight); *Leucaena leucocephala*, 1 and 2 kg/m^2; *Terminalia brownii*, 1 and 2 kg/m^2; and control (no leafy material applied).

The leafy material was applied about 2 weeks before planting and incorporated into the soil immediately to prevent the wind from blowing it away. To minimize the influence of slope, small ridges were made around each plot.

For the test crop, beans (*Phaseolus* spp.) and maize (*Zea mays*) were applied. Each plot had one row of 10 bean plants, with 15 cm between each plant. Each plot had one row of 6 maize plants, with 30 cm between each plant.

To observe the effect of continued green manuring on the same piece of land, the experiment was performed in March 1984 at the onset of the long rains, in October 1984 during the short rains, and in both seasons of 1985. To screen as many species and rates as possible with the limited amount of land available, very small plot sizes were used. This technique exposes relative differences between treatments rather than absolute differences. For this reason, yield values cannot be extrapolated to a per-hectare basis.

A larger experiment was established in May 1985 to obtain more reliable yield values (Arap-Sang and Hoekstra 1986a, c). To date, only one season's results have been analyzed.

Hedgerow trials

On-farm hedgerow trials were initiated during the short rains of 1985 on one farmer's plot. Two species were used: *Gliricidia sepium* and *Leucaena leucocephala*. Three more plots have been prepared for trials with *Sesbania sesban*, *Calliandra calothyrsus*, and *Gliricidia sepium*. The trials have four main objectives:

- to study the effect of hedgerows on maize yield;
- to study the effect of different intrarow tree spacings on the yield of maize in the alleys;
- to study the effect of proximity to the hedgerows on the yield of maize; and
- to study the "side of hedge" effect on maize yield.

Results and discussion

Leaf-manuring trials

Results of the first three cropping seasons with maize have been reported in detail by Arap-Sang et al. (1985). *Leucaena leucocephala* at 2 kg/m^2, *Terminalia brownii* at 1 kg/m^2, and *Cassia siamea* at 2 kg/m^2 gave the best results for plant height, leaf area index, and grain weight. *Terminalia* at 2 kg/m^2 somehow inhibited these parameters; the reason for this observation is still unknown.

Preliminary results from trials elsewhere in Machakos District gave green matter yields for *Leucaena* of about 1.5 kg/tree per season at an average intrarow spacing of 0.62 m and between-row spacing of 3.5 m. Per-hectare production of leafy material per season was, therefore, approximately 6 900 kg; distributed over a crop area of 6 600 m^2 (one-third of the total area being occupied by the hedges), application rate was about 1 kg/m^2. At this rate, the relative yield of maize per unit of crop area increased by only 22%. In the case of *Leucaena*, this would be insufficient to offset the reduction in yield as a result of land loss (33%). No biomass figures are available for *Terminalia*.

During the fourth cropping season, a significant, positive difference (36–122%) was observed between treated and control plots. Whether this improved performance can be attributed to the cumulative green-manuring effect or to other factors may be determined through a proper soil analysis (in progress). The negative effects of *Terminalia brownii* prunings applied during the third cropping season at 2 kg/m^2 were not observed in the fourth cropping season. No conclusive results have been obtained over the three cropping seasons with beans as the test crop.

In the large-field trial, the response of maize yield to the application of green manure from tree leaves was inconclusive during the first cropping season (Arap-Sang and Hoekstra 1986c). The response from *Leucaena* was directly related to treatment level. It is expected that the treatment effects will be more consistent once soil fertility has become a more critical factor because of continuous cropping.

On-station hedgerow trials

Because hedgerow trials are still in the developmental stage and because of their limited scope, they have prompted no definite conclusions. Most of the preliminary results are of an exploratory nature, offering some interesting clues to how the system might perform as well as clues to some of the factors affecting performance.

During the development phase of the alley cropping system, hedges seem to have had both positive and negative impacts on the stover and grain production of the maize grown in the alleys. In the first three cropping seasons, the positive impact outweighs the negative. The positive impact is probably due to the sheltering effect of the hedges. Wind direction (east–west) is almost perpendicular to the hedgerow direction (north–south). With an average pruning height of 50 cm, the maize plant between the hedgerows can obtain complete protection. Especially during the early growth stages, when the individual maize plants are not yet tall enough to provide each other shelter from wind, the plants between the hedges could be at an advantage compared with the maize plants in the control plots.

In the fourth and final cropping season, the shelter offered by the hedges is neutralized by its negative impact on the maize. Such an impact is clearly related to the growth of the hedges and is likely due to competition for moisture between the hedges and the adjacent rows of maize. These findings indicate that maize loss during the early days of hedgerow development can be minimized, provided the hedgerows have the proper orientation with respect to wind direction.

With regard to the two in-row spacings of *Cassia siamea*, during hedgerow development, no significant differences were observed in their interaction with the maize rows. The 0.25-m intrarow spacing, however, showed a considerably higher mortality rate in periods of drought; at the same time, more labour and seedlings were required to establish this plot (compared with the 1-m spacing). To determine the advantages and disadvantages of each spacing requires further monitoring in the next phase.

The better performance of the outer rows compared with the centre row (when the hedge is being established) is probably due to increased availability of moisture, sunlight, and nutrients close to the hedgerows. Therefore, it may be advantageous to increase the maize population near the hedges during the first cropping season and use this improved microenvironment to minimize losses. Care should be taken, however, that the added competition to the seedlings should not seriously hamper their growth. Part of the additional soil moisture in the hedgerow zones may disappear when hedges are established through direct seeding rather than seedlings (this requires less land preparation, resulting in less infiltration).

In summary, two aspects deserve special attention; both have an important bearing on the feasibility of the alley cropping system.

- The losses in crop production during the development period of the hedges are less than anticipated, making the system more attractive to farmers.
- The development period of the hedges was longer than expected, making the system less attractive to farmers; however, experimentation elsewhere in the District has shown that quicker results can be obtained.

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Fodder production from *Leucaena leucocephala* intercropped with maize and beans in Tanzania

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Abstract — From 1980 to 1983, a study was carried out at Mafiga, Morogoro, in the subhumid area of Tanzania, to determine the effect of intercropping Leucaena leucocephala *with maize and beans on food crops and fodder production. Crop yields were assessed for four cropping seasons. The implications of the results to meeting livestock fodder needs and the effects on long-term soil productivity are discussed.*

Introduction

The potential of *Leucaena* forage for livestock, poultry, and fish in rural communities is well known (Ghatnekar et al. 1983; NAS 1980). The value of *Leucaena* lies in its high nutritional quality. The nutrient and roughage content for ruminant feed is comparable to alfalfa, with a digestibility of 50–87% (Oakes 1968) and a protein content of 25–34% (Brewbaker 1975; NAS 1984). The amino acid content is well balanced, and the leaves contain twice the amount of carotene, riboflavin, and vitamin K per unit dry weight as those of other legume feeds (NAS 1984). Improvements in live-weight gains of livestock have been achieved with *Leucaena* feed in various parts of the tropics (Malynics 1974; Jones and Bray 1983; Wong and Devendra 1983).

Leucaena is prolific in foliage production. According to NAS (1984), annual dry matter yields range from 2 to 20 t/ha. Higher yields of up to 50.9 t/ha are being achieved in highly intensive, monocultural fodder-production systems with populations of over 200 000 plants/ha (Hegde 1983).

Leucaena foliage can also be used as organic fertilizer (Brewbaker 1975; Palled et al. 1983). Its high foliage yield (Bottenberg 1981) and efficient nitrogen fixation ability (NAS 1984) can contribute significantly toward soil conservation and improvement. However, patterns of tree, crop, and animal interactions that can best use the benefits from the overall system have not yet been fully established. The objectives of this study were

- to compare the growth of *Leucaena* in monoculture and when intercropped with maize and beans,
- to compare the yields of maize and beans grown as sole crops or intercropped with *Leucaena*, and
- to ascertain potential for fodder production.

Site

This study was carried out at the experimental site of Sokoine University of Agriculture at Mafiga, Morogoro, Tanzania (6°50' S, 37°38' E; 520 m above sea level). The area lies within the Ngerengere Valley with a north-easterly slope of less than 5%. The sandy soils are developed from alluvial deposits. With a mean annual rainfall of 740 mm, the area conforms to a subhumid, bimodal climate. Short rains fall during November–December and long rains during March–May, with 92% of all the rain falling within the 7-month period from November to May. Mean daily temperature highs vary from 28 (June) to 34°C (December); lows range from 13.9 (July) to 23°C (December).

Experimental design

The area was ploughed, harrowed, and planted with *Leucaena leucocephala* cv. Hawaiian Giant and interplanted with either maize (*Ilonga* composite) or beans (cv. Canadian Wonder). The population density of the *Leucaena* varied. The experiment was laid out using a split-plot design. Maize, beans, and clean-weeded (control) treatments formed the main 0.2-ha plots. *Leucaena* spacings were 1 × 3 m (3 333 trees/ha), 1 × 4 m (2 500 trees/ha), 1 × 5 m (2 000 trees/ha), and 1 × 6 m (1 667 trees/ha), with no-tree control plots forming the subplots. Subplot size was 432 m^2. The experiment was replicated four times.

The trees were planted in March 1980. Tree rows were aligned in an east–west orientation. In April 1980, the crops were interplanted in the spaces between the tree rows (alleys) at spacings of 75 × 30 cm for maize and 40 × 20 cm for beans. Avenues free of maize (50 cm wide) or free of beans (20 cm wide) were provided on both sides of each tree row to limit suppression of the trees by the crops, particularly during tree establishment. The crops were interplanted in the subsequent cropping seasons.

With each cropping season, fertilizer was applied. The maize crop received 84 kg N/ha (as sulphate of ammonia) and 40 kg P/ha (as triple superphosphate); bean plots received 42 kg N/ha and 40 kg P/ha. Phosphate was applied in pits at the time of crop sowing. Half of the nitrogen was applied 4 weeks after sowing and the remaining half applied at tasseling time. Weeding was done whenever necessary. Plots with food crops were hand hoed and plots without crops were tractor harrowed, supplemented with hand hoeing in areas inaccessible to the harrow.

Tree growth, fodder production, and crop yields were assessed. Tree-growth and fodder-production assessments were restricted to the seven centre trees from each of the three centre rows of each subplot. Fodder-production assessments were initially done at 14 months through prunings from the lower halves of trees. After 23 months, the trees were clipped 1 m above the ground and all the fodder from the clippings was determined. Subsequently, clippings for fodder assessment were done at 3-month intervals, to the age of 41 months, by maintaining 1 m high hedgerows.

The fodder (leaves, flowers, pods, and young shoots) was weighed green and oven dried at 70°C. Nutrient content and nutrient removal from production sites through fodder harvests were estimated by using subsamples. These samples of oven-dried fodder were milled in a Wiley mill and nitrogen content was determined using the macro-Kjeldahl method (Bremner 1965). Some of the samples were ashed in a muffle furnace at 450°C for 3 h and extracted with 6 *N* HCl. Phosphorus was determined colorimetrically (Bray and Kurtz 1945). Potassium, calcium, and magnesium were determined using atomic absorption (Uriyo and Singh 1974). Yields of maize and beans were assessed for four cropping seasons.

Results and discussion

Over a period of 41 months, *Leucaena* plants yielded an average of over 3 t/ha of fodder per year. Fodder yield from bean-intercropped plots was significantly higher with the 26- and 28-month sampling only. Monthly yields, however, varied widely with season.

Table 1. Mean annual fodder yield from *Leucaena* hedgerows intercropped with maize and beans at Mafiga, 1980–1983.

Management regime	Fodder yield (t/ha)
Clean weeded	2.9
Intercropped with bean	3.4
Intercropped with maize	2.8

Table 2. Mean annual per-tree and per-hectare fodder yields from *Leucaena* at various hedgerow spacings, intercropped with maize and beans at Mafiga, 1980–1983.

Hedgerow spacing (m)	Fodder yield: Per tree (kg/tree)	Fodder yield: Per hectare (t/ha)
1 × 3	1.00d	3.3e
1 × 4	1.19c	3.0e
1 × 5	1.50b	3.1e
1 × 6	1.67a	2.8e

Note: Values within the same column followed by the same letter are not significantly different ($P < 0.05$).

Intercropping with food crops had no apparent effect on fodder yields (Table 1). Hedgerow spacing, similarly, had little influence on the per-hectare fodder yield (Table 2). It should be noted, however, that the per-tree fodder yield increased in direct proportion with hedgerow spacing. The larger number of plants in close spacing, however, compensated for lower per-tree fodder yields.

The mean nutrient percentages in the fodder harvested were as follows: N, 2.88%; P, 0.11%; K, 1.38%; Ca, 0.67%; and Mg, 0.28%. Statistical analysis of the data showed that management regimes have no significant influence on nutrient removal. However, large amounts of nutrients were removed when the fodder was harvested (Table 3). The future effects of these drains on long-term fodder yields and general site productivity require close monitoring.

Crop yields for the four cropping seasons (Table 4) showed that, during the first cropping season, when the trees were still small (<1 m), hedgerow spacings did not influence either maize or bean yields. In the second cropping season, the trees in the hedgerows were tall enough to shade the crops (4.6 m in May 1981, the peak of the cropping season); maize yields in all the maize–tree plots were significantly reduced. Effects on bean yields were not as pronounced.

Yields of both maize and beans, once the clipping regime had been implemented, were not significantly influenced by the presence of the hedgerows. This confirms that the negative influence of the trees on maize yields observed in the second cropping season was the result of shading rather than competition for moisture and nutrients.

Table 3. Mean annual nutrient removal (kg/ha) with fodder harvests from *Leucaena* hedgerows intercropped with maize and beans during the first 41 months at Mafiga, 1980–1983.

Management regime	N	P	K	Ca	Mg
Clean weeded	88	4	42	18	8
Intercropped with beans	95	5	48	20	8
Intercropped with maize	80	5	37	23	9

Table 4. Mean yields (kg/ha) of maize and bean from the alleys between *Leucaena* hedgerows during the first four cropping seasons at Mafiga, 1980–1983.

Hedgerow spacing (m)	Maize				Beans			
	1980	1981	1982	1983	1980	1981	1982	1983
1 × 3	1681	131	121	361	463	105	77	258
1 × 4	1744	92	155	395	371	85	80	270
1 × 5	1771	82	162	459	363	125	63	302
1 × 6	1336	173	166	534	410	137	77	197
Control	1678	626[a]	169	583	402	177	72	309

[a] Significantly different ($P < 0.05$) from other values in the column.

The effect of the low, irregular, and uncertain rainfall characterizing the Mafiga area during most of the study period is apparent from the low crop yields observed during the last three cropping seasons (1981–1983). In contrast, crop establishment, especially of maize, coincided with good rainfall distribution and intensity in the first cropping season (1980).

From these results, it is apparent that the growth and yield of *Leucaena* fodder at Mafiga is lower than those reported from the more humid regions with their more intensive monocultural production systems (Takahashi and Ripperton 1949; Hegde 1983; Krishnamurthy and Gowda 1982). Site variations (Hu and Kiang 1982), and management approaches (NAS 1984) have been shown to greatly influence the growth pattern and yields of *Leucaena* trees.

The fodder yields obtained in the present study are within the annual range of 2–20 t/ha that has been reported (Jones 1979; NAS 1984). These yields are considered reasonable for the semihumid environment for the range of tree densities used (1 667–3 333 trees/ha). The long-term implications of the associated nutrient removal through fodder harvest on field fertility requires close monitoring.

Intercropping with agricultural crops insures that the planted trees are maintained and protected through weeding, which will reduce the chances of fire. *Leucaena* planted in this way could prove attractive and this system needs to be encouraged in the rural and near-urban communities where crop production goes hand in hand with raising livestock. For fodder production, *Leucaena* hedgerows spaced at 6 m with the crops grown in the intervening alleys provides an optimum intercropping system that maximizes the benefits of the overall system under conditions similar to the conditions of this study.

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Alley farming in central Togo

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Abstract *— The benefits of alley cropping and establishing forage banks on farms that use oxen and keep small ruminants are discussed.*

Introduction

Alley cropping food crops with pigeon pea and *Leucaena* can be an important source of animal feed on farms with a pair of oxen or small ruminants. Having sufficient forage, the oxen can be used for transport during the dry season instead of being sent to pasture. They will be able to spend more time in the stable, thereby increasing manure production. At the start of the rainy season, the oxen will be healthy and strong so that ploughing can be done efficiently.

Experimental design

Leucaena was direct seeded in 4 m rows at 14 sites in northern Togo. Pigeon pea (local, photosensitive variety) was intercropped with maize and planted at a high density (40 cm between rows). Maize was planted at 41 666 plants/ha; pigeon pea, at 83 333 plants/ha.

Six types of *Leucaena leucocephala* (cv. K-28, K-8, K-132, K-128, Cunningham, and a local variety) were evaluated after transplanting; at one site, cv. Cunningham and cv. Improved Peruvian were direct seeded and evaluated. The local variety was transplanted 1 m apart in a forage bank plot of 100 m^2 as part of an intensive sheep-raising program on 10 farms.

Results

Although emergence was excellent, growth was slow at all but two centres. Regardless of the height attained, the *Leucaena* was browsed and the plants were broken by cattle and small ruminants after the rainy season. Intercropped pigeon pea reduced maize yield by 28% and gave a grain land equivalent ratio (LER) of only 76%. Forage fresh weight ranged from 1 to 2 t/ha; the weight of leaf litter and

Table 1. Plant height (m) of several Hawaiian Giant *Leucaena* cultivars in Central Togo.

Transplanted		Direct seeded	
Cultivar	Height	Cultivar	Height
K-28	2.84±0.22	Cunningham	1.57±0.24
K-8	1.99±0.32	Improved Peruvian	1.30±0.30
K-132	1.87±0.25		
K-128	1.79±0.34		
Local	0.94±0.08		
Cunningham	1.82±0.46		

fuelwood ranged from 3 to 5 and from 5 to 8 t/ha, respectively. The high pigeon pea density drastically reduced weed competition. The close spacing made it difficult for animals to fell the plants, allowing for grain and forage harvest in February, the middle of the dry season. The five Hawaiian Giant cultivars of *Leucaena* showed good growth (Table 1).

There was a slight height increase (0.25 m) as a result of transplanting in cv. Cunningham. The local *Leucaena* variety is a slow-growing recumbent type. The local variety, when transplanted in protected enclosures, failed to grow satisfactorily, and the majority of the plots were abandoned as the farmers concentrated on their field crops.

Conclusions and future plans

The regrowth and ability to withstand browsing of directly seeded *Leucaena* will be observed in its 2nd year. First-year trials will be placed in farmers' fields in which the *Leucaena* will be seeded in the same row as maize, sorghum, or pigeon pea.

In the 2nd year of the pigeon pea trial, every fifth row will be kept to create 4-m alleys. Attempts will be made to measure the residual effect of the pigeon pea on a subsequent sorghum crop. First-year trials with pigeon pea will be started with farmers, with pigeon pea density reduced by half (41 666 plants/ha); three to four cuttings will be made during the year to increase forage yield and reduce competition with the maize.

A maize–pigeon pea–*Leucaena* intercrop will be evaluated in the forage banks. It is hoped that the pigeon pea will provide 1st-year forage, the maize will encourage the farmers to weed on time, and, once established, the *Leucaena* will provide sustained forage production. After 1 or 2 years, the forage bank enclosure can be moved to a new site. Local materials (pigeon pea and sorghum stalks) will also be evaluated as fencing materials.

Alley cropping maize with *Leucaena leucocephala* in southern Togo

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Abstract *— The field trial carried out in southern Togo using* Leucaena *hedgerows intercropped with maize is discussed.*

Introduction

Soils in southern Togo are classified as ferralitic and are commonly called "terre de barre." These lands were productive in the past but they have become degraded as a result of overuse. Alley cropping was introduced as a possible technique to rehabilitate and prevent the soils from further degradation as well as to alleviate nitrogen-deficiency problems. A field trial was carried out at Glidji in southern Togo to study the nitrogen contribution of *Leucaena leucocephala* hedgerows to alley-cropped maize and the effect of alley cropping on soil nutrient changes.

Methodology

Leucaena hedgerows were established using cv. K-28. During the 1st year, seeds were planted in five rows at a spacing of 4 m. During the 2nd year, hedges were pruned and the prunings were applied to each plot. Maize was planted in the alleys.

Results

Statistical analyses of the maize yield data showed that maize plants responded positively to nitrogen application from urea and prunings (Table 1). Nitrogen application improved plant growth and grain yields. The highest yield was obtained with the application of 80 kg/ha and prunings; this treatment increased maize yield by 1 370 kg/ha over the control. Maize yield was higher in treatments receiving *Leucaena* prunings at high N rates, indicating higher productivity of applied N with the addition of prunings.

Table 1. Effect of nitrogen application on maize grain yield alley cropped with *Leucaena* in southern Togo.

Treatment[a] (kg N/ha)	Grain yield (kg/ha)	N rate (kg/ha)	Grain yield (kg/ha)
0 (control)	1570	0 (control)	1570
0 (P)	1878	40	2233
20 (P)	2150	80	2689
40 (P)	2487	120	2868
80 (P)	2941		
CV (%)	9.72	CV (%)	10.23
$LSD_{0.05}$	233	$LSD_{0.05}$	243

[a] P, prunings added; (CV, coefficient of variation; LSD, least significant difference (P < 0.05).

Conclusion

Yield data from alley cropping trials with maize and *Leucaena leucocephala* at Glidji in southern Togo showed that, even under low-rainfall conditions, the addition of *Leucaena* prunings can reduce nitrogen fertilizer use.

Adoption of alley cropping in the Province of Atlantique, Benin

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Abstract—*Alley cropping has been tested and adopted by the Centre of Regional Action for Rural Development (CARDER-Atlantique) in Benin. Results of experiments carried out over 2 years have shown that a farmer using this technique can increase maize yield by 35–52% in the main season and by more than 50% in the minor season. The prospect is good for extending this technique to farmers in the Atlantique Province of Benin.*

Introduction

The Centre of Regional Action for Rural Development (CARDER-Atlantique) is a national and regional development institution whose research objective is to examine the adoption possibilities of potential cropping patterns developed by international and national research institutes. Its main aim is to promote agricultural development through innovations that will overcome the obstacles to agricultural improvement in the Province of Atlantique in the southeastern region of Benin.

Rainfall in Atlantique varies between 800 and 1 200 mm/year. The population density is about 350 people/km^2. The subsequent intensive land use has caused a rapid deterioration of the soil structure, a decrease in fertility, and a reduction in the fallow period. Because Atlantique Province is located on the coast, it has been subjected to rapid urbanization, gradually reducing the amount of arable land.

The CARDER-Atlantique project is trying to achieve food self-sufficiency through research and utilization of alley cropping systems, systems that will allow intensive land use with minimal inputs as a substitute to natural fallow. The project has adopted the alley cropping system developed at the International Institute of Tropical Agriculture. The following woody species were used in the trials: *Leucaena leucocephala*, *Gliricidia sepium*, and *Cajanus cajan*.

Results

Adaptation tests of various species and varieties are being carried out in the Support Research Farm at Abomey-Calavi (20 km from Cotonou) and in some farmer-managed fields. The maize cultivar EV 74835R was used for the trials,

Table 1. Mean maize yields (kg/ha) from alley cropping trials, main crop.

Treatment	Maize grain yield	Relative yield
Control	2685	100
Leucaena		
One mulching	3840	143
Two mulchings	4076	152
Gliricidia, two mulchings	3840	143
Cajanus, two mulchings	3625	135

Table 2. Mean maize yields (kg/ha) from alley cropping trials, minor season.

Treatment	Maize cob yield	Relative yield
Control	1018	100
Leucaena		
One mulching	1812	177
Two mulchings	1747	172
Gliricidia–Cajanus, one mulching	1542	151

which were conducted in the main cropping season, from April to July. Results of trials over a 2-year period show an increase of 35–52% in comparison with the check (Table 1). Results from the 2nd season (September–December) using NH (a composite maize strain) show an increase in yield of about 50% (Table 2).

Results of observation trials on the growth of various woody leguminous species and varieties also showed large differences in early growth. In 1 year, *Leucaena leucocephala* mean plant heights ranged from 2.3 to 3.8 m. *Acacia auriculiformia* reached a mean plant height of 2.32 m. *Gliricidia sepium* established from cuttings reached a mean height of 1.96 m; from direct seeding, the mean height was only 0.76 m.

Conclusion

The extension of the alley cropping system as an alternative to natural fallow can be carried out in the Province of Atlantique, Benin.

The role of *Leucaena leucocephala* in farming systems in Nusa Tenggara Timur, Indonesia

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Abstract *— Nusa Tenggara Timur (NTT) is one of the driest provinces in Indonesia. Agriculture is seriously restricted by the long dry season, steep slopes, and low soil nutrient status. Shifting cultivation is still widely practiced, resulting in soil erosion and land degradation. Various programs introduced in the past by the Dutch colonial government to replace shifting cultivation (e.g., partial mechanization or intensive agriculture using high inputs) have failed.* Leucaena leucocephala *was introduced in NTT during the 1910s to improve traditional farming systems. Although it is widely grown in the region, a breakthrough in its use did not occur until the 1970s with the introduction of the Lamtoronisasi and the Paronisasi programs, and the Hawaiian Giant strain, known locally as* lamtoro-gung. *The local varieties (Hawaiian type) are being used successfully for soil-conservation programs on hilly land at Sikka on the Island of Flores and to fatten cattle at Amarasi in West Timor.*

Introduction

The province of Nusa Tenggara Timur (NTT) occupies the eastern part of the Lesser Sunda Islands, which includes West Timor, Flores, Sumba, and many other small islands. The provincial administration is divided into 12 regions called Kabupatens. The total land area is about 50 000 km^2 with a population of about 3 million. The population density varies between regions. Kabupaten Sikka on the island of Flores is the most densely populated region with an average density of 150 people/km^2; central Sikka has more than 400 people/km^2. Kabupaten Sumba Timur on the island of Sumba has the lowest population density (25 people/km^2).

NTT occupies a special position in the Indonesian archipelago: it has the lowest average annual rainfall (1 000–2 000 mm), especially on the northern slopes, which have over 6 dry months. Agriculture, the predominant form of land use in this region, is seriously restricted by the long dry season with irregular amounts of rainfall, steep slopes, and low soil nutrient status. The intensity of the rains also causes severe erosion, floods, and landslides. Slash-and-burn agriculture is still widely practiced on about 43% of the total arable area of this region. Combined with other forms of upland farming, dryland agriculture makes up about 72% of all land cultivated each year. Slash-and-burn farming with no efforts at conserving soil, together with overgrazing, have resulted in extensive land degradation over about 48% of the province's land area. This is marked by extensive grass savannas and severely eroded hills, many of them covered with *Imperata cylindrica*.

The low average agricultural productivity, sometimes marked by crop failures, has resulted in a low per-capita income. This has prompted the government, even under Dutch rule, to introduce improvements in traditional agricultural practices and farming systems. At the end of the 1800s, coconut was introduced as a monocrop at sea level and on steep hills to an altitude of 600 m. This resulted in serious soil erosion and environmental degradation of the hilly lands.

Cattle was introduced from the islands of Java and Bali at the beginning of the 1900s with the intention of inducing the native population to switch to commercial stock keeping. Although large numbers of cattle can now be found on the islands of Timor and Sumba, this goal has not been achieved (Metzner 1977). The cattle adapted well to the local situation but did little to solve the problem of feeding the people (Piggin and Parera 1984). Moreover, the heavy concentration of free-grazing animals has led to overgrazing in many areas.

Many failures were also observed with several other projects, e.g., partial mechanization to help farmers farm larger areas (as in Sekon on the island of Timor) and resettlement schemes with intensive cultivation at lower altitudes for shifting cultivators who lived in scattered mountain settlements. Later, it was felt that the problems could only be overcome by a complete change in farming methods: the incorporation of *Leucaena*, a plant already known in the area (Metzner 1976).

Introduction of *Leucaena leucocephala*

Leucaena, a promising forage and tree crop for the tropics, was introduced by Spanish merchants to Asia from Central America sometime between 1565 and 1825. A bushy, Hawaiian strain was brought to the Philippines by these merchants (NAS 1984). Dutch plantation owners imported *Leucaena* to the island of Java during the 1800s to be used as shade trees for plantation crops such as tea, cocoa, cinchona, coffee, and vanilla. It was later observed that *Leucaena* could be used as a support for climbing crops such as pepper and vanilla, as firewood and forage, for green manure, or for erosion control when planted in rows along the contour lines of hillsides. Because of its many functions, particularly erosion control, *Leucaena* was introduced to NTT during the 1910s as part of an effort to replace shifting cultivation. The species has adapted well to the dry, harsh conditions of the province; however, because of its rapid growth, farmers found it difficult to accept at first. Now, however, *Leucaena* plantations can be observed in various areas of NTT.

On the island of Flores, the first *Leucaena* introduction was made in the mountainous Lio area (about 1930). It has since expanded extensively. This vast expansion was due to the realization by the farmers that *Leucaena* was well suited to their traditional agricultural practices. Soil-fertility restoration under *Leucaena* took less time. From September to April, farmers clear small plots in the *Leucaena* forest for upland rice and maize production.

On the island of Timor in the 1930s, *Leucaena* was planted on abandoned fields around Baun as an experiment under the guidance of the Dutch administrator (Ormeling 1955; Metzner 1981). Since then, the plant has been established widely. A traditional ruling in 1932 obliged every farmer in Amarasi on the island of Timor to plant contour rows of *Leucaena* not more than 3 m apart in cropped areas before the land was abandoned. Failure to comply carried the threat of a fine or jail sentence. Planting expanded eastward to Oekabiti and Burain as the local decree was implemented in the early 1940s (Metzner 1981).

This local regulation was reinforced in 1948 by the government, which compelled all shifting cultivators to plant *Leucaena* along contour lines (Ormeling 1955). Today, *Leucaena* has formed such a solid cover that, in Amarasi, the contour lines are not evident. This is because the hedges were not trimmed and the plants quickly colonized the spaces between the hedgerows (Metzner 1981). According to Ormeling (1955), the total area under *Leucaena* in Kupang district on the island of Timor was 465 ha in 1948, with 437 ha located in Amarasi. A more recent estimate (Metzner 1981) shows that *Leucaena* covers about two-thirds of the Amarasi district. This has greatly helped in controlling the weed *Lantana*. Jones (1983) and Piggin and Parera (1984) reported that the area under *Leucaena* was spreading south and east of Amarasi.

The eastern and the driest part of Sumba is mostly hilly and barren. At the Isyak Daoriwu garden close to Waingapu, an area of about 3 ha has been planted with *Leucaena* since 1936. This small *Leucaena* field provides a contrast to the surrounding barren area and illustrates the potential that trees can have on the environment.

Lamtoronisasi

Lamtoronisasi is a term widely used, particularly in the Sikka region, in which the Hawaiian bushy type of *Leucaena* is used to create hedgerows of indirect terraces on sloping land to control erosion (Fig. 1). In 1978, when Hawaiian Giant was introduced, this term also encompassed the Salvador and Peruvian varieties (Parera 1980).

Efforts to control erosion in the Sikka region began in 1966 with the development of bench terraces. Because the hard work required had no immediate payoffs, however, the local population was reluctant to adopt this practice. Father H. Bollen, a German priest, was impressed with the potential of *Leucaena* for erosion control and rehabilitation of critical lands. He established a small trial plot by planting contoured rows. One year later, a local farmer also established a small garden. The stable yields in this garden over a 3-year period from 1969 to 1971 prompted the establishment of an indirect terracing demonstration plot using contoured rows of *Leucaena* planted at 5-m intervals.

A year after the establishment of the *Leucaena* hedgerows, clove trees were planted between the *Leucaena* rows. The success of this experiment is one of the best examples of *Leucaena*'s ability to grow in harsh conditions, with subsequent rehabilitation of the soil so that valuable crops can be planted.

Stimulated by these successes, the local administrator of Sikka district directed that these practices be expanded to other areas in the district. A Soil Erosion Control Team for Sikka district was set up in 1973. The team was charged with

Fig. 1. ***Leucaena*** **hedgerows are used to stabilize hilly and steep lands in Sikka District, Flores, Indonesia.**

training farmers and arranging for the purchase and distribution of tools such as hoes and water levels. The term *lamtoronisasi* (Parera 1980) was introduced to distinguish this technique from other forms of erosion control.

To promote *lamtoronisasi*, the national food crop intensification program (BIMAS), which has been operating in Sikka district since 1974, makes improved seeds, inputs, and credit facilities available only to farmers who have planted *Leucaena* on their land (Parera 1982). The same arrangements were made for those farmers wanting to buy seedlings of cocoa or cloves from the Agricultural Extension Service. The larger crop yields derived from the project made this exercise attractive to local farmers (upland rice yields increased from 500–700 kg/ha with the traditional system to 2–3 t/ha; maize yields more than doubled). The farmers also made more money by growing cloves, which fetch higher prices than the earlier-introduced coconut.

All these factors have led to more *Leucaena* being planted since 1974 to create indirect terraces and to support bench terraces that were already there (Fig. 1). By 1982, about 20 000 ha of hilly lands had been terraced and more than 2 million *lamtoro-gung* (Hawaiian Giant) had been planted in Sikka district.

The effectiveness of *Leucaena* hedgerows in reducing erosion and runoff largely depends on layout and timeliness; the hedgerows must be planted on the contour at the start of the short rainy season (±4 months). The seeds of the Hawaiian type are sown directly in raised beds in the fields; seeds of Hawaiian Giants are first grown in polyethylene bags and then transplanted. The contours, spaced 3–5 m apart, are determined using a water level or a simple A-frame, after which raised beds of

20 × 10 cm are constructed. Untreated seeds are sown in the beds at a seeding rate of 70–100 kg seeds/ha. The less vigorous Hawaiian type is more suitable for terrace hedgerow planting.

Periodic pruning of the hedgerows (at 75–80 cm height) prevents *Leucaena* from becoming a weed, a development that made it unacceptable to farmers in the past. Pruning is done after the plants are more than 1 year old. In many cases, poor performance of hedgerows can be traced to too early pruning. In burned-over areas, the regrowth of *Leucaena* can be stimulated by pruning.

Although not many farmers in the Sikka District intentionally use *Leucaena* prunings as green manure for their crops, the leaves drop around shrubs during pruning. The manuring effects are the same as in deliberate mulching, with the upper side of the terraces benefiting more from the practice (Metzner 1976).

The presence of *Leucaena* hedgerows also improves microclimate. Some farmers have recognized these changes and have begun cultivating crops, such as peppers and cocoyams, that could not be cultivated before (Parera 1983). Single *Leucaena* stems in the hedgerows spaced 3 m apart were sometimes left uncut and used as supports for climbing crops such as vanilla.

Leucaena prunings are also fed to chickens and pigs in Flores. Cattle have not traditionally formed a significant role in the livestock industry in Flores. Efforts to encourage cattle farming began in 1967 with the introduction of 100 head of Bali cattle under a government credit program. According to Cunha (1982), however, there were only 50 cattle in Sikka in 1970, owned mainly by the Department of Animal Husbandry and the Catholic Mission.

The cattle industry received another stimulus in 1978 with the introduction of the more productive Hawaiian Giant strain, which are planted widely in uncropped areas and are suitable as material for fodder banks. Further introductions of 1 500 head of Bali cattle over the next 2 years brought the cattle population to over 2 000 head by mid-1982 (Cunha 1982). It is anticipated that, in the future, the *Leucaena* farming systems in Sikka will also include intensive cattle production and fattening, using a cut-and-carry system. Farmers are familiar with tethered livestock, as horses are traditionally tied (Piggin and Parera 1984).

Paronisasi

Bali cattle was introduced to Nusa Tenggara Timur around 1912 to supplement periodic food shortages, usually the result of incorrect agricultural practices (Monny 1979). This objective was not wholly achieved, however, as the large increase in population and livestock was not accompanied by a corresponding intensification of cultivation methods (Metzner 1977). With more cattle to feed (about 440 000 in 1977), fodder supply became a problem (Huitema and Doormal 1946). The traditional practice of burning and overgrazing reduced not only the forage quality but also the carrying capacity of these grasslands. Abortion and death among calves are common in the dry season.

At Amarasi on the island of Timor, the condition was aggravated by the presence of *Lantana camara*, a woody shrub first observed in Timor around 1912. It was probably introduced as a potted plant or with cattle to Kupang. It spread rapidly

Fig. 2. Fattening cattle on *Leucaena* fodder.

eastward between 1915 and 1935. By 1949, about 80% of Amarasi District was covered by the weed (Ormeling 1955; Metzner 1981).

Livestock owners and food crop farmers have differing opinions about the plant. To livestock owners, the plant is a weed as it dominates the grassland and is not eaten by the livestock. Metzner (1981) suggested that the decline in livestock numbers (cattle, water buffalo, horses) in Amarasi from 6 000 in 1916 to 4 000 in 1948 was largely due to *Lantana* infestation. Ormeling (1955) reported lower livestock numbers in the early 1950s in Amarasi (60/km^2 and 50 per 1000 inhabitants) compared with the Timor island average (170 and 450, respectively). However, the shifting cultivator likes *Lantana* because it grows rapidly and can reduce fallow periods from 15 to 5 or 6 years. It provides a rapid soil cover, maintains good soil structure, and reduces the growth of other weeds. Thus, land-preparation time in subsequent crops is reduced (Ormeling 1955). Under the influence of powerful cattle owners, attempts were made around 1955 to control *Lantana* biologically using *Teleonemia lantanae* and herbicides (Ormeling 1955; Metzner 1981). These methods had little effect, and control was ultimately achieved by replacing *Lantana* with *Leucaena*, an acceptable solution to both herders and farmers (Piggin and Parera 1984).

In 1971, cattle production in Timor was stimulated by the provincial government's successful introduction of *paronisasi* (Fig. 2). In this program, cooperating farmers are given a bull to feed on crop residues and plantation products. When the animal reaches export weight and is sold, the profit is shared by the government and the farmer. This program has become the basis of an extensive private program in which exporters and individuals with large herds provide animals for feeding and share the profits with the farmer doing the feeding (CIDA 1980).

Because *Leucaena* is available in abundance for use as fodder in Amarasi, that district benefits the most from this scheme. According to Metzner (1981) and Jones (1983), the average farmer in Amarasi supports a family of about six people and owns 2 ha of land on which *Leucaena* is established at a density of about 10 000 trees/ha. One-third of the farmer's land is used to plant maize and other food crops in a 3-year rotation scheme; the remaining two-thirds is used to provide fodder for the tethered cattle.

The cattle are fed 15–20 kg of *Leucaena* fodder and other legumes each morning and afternoon. Over 100 kg/day of browse is required for a family with three cattle. *Leucaena*, densely planted on 1 ha, can usually supply this requirement. Cattle and goats that were fed entirely on *Leucaena* for 6 months did not show any symptoms of mimosine toxicity. One-year-old cattle (Fig. 2) bought at the local markets for about IDR 75 000 (in 1985) are fattened for about 18 months and sold for about three times the purchase price (in December 1988, 1750 Indonesian rupiah [IDR] = 1 United States dollar [USD]).

Leucaena also benefited other crops such as banana, pawpaw, and coconut. These crops are now intercropped with *Leucaena*. Banana stem is fed to cattle as a source of water.

Extending alley farming

The impact of *lamtoronisasi* in Sikka and *paronisasi* in Amarasi has prompted government and private agencies in other districts to use *Leucaena* to promote soil fertility and increase agricultural production. The Provincial Development Programme is run by the Directorate of Regional Development, Ministry of Home Affairs, and the United States Agency for International Development. Together, the two agencies run three projects on the island of Timor, one on the island of Flores, and one on the island of Alor. One aim of these projects is to help resource-poor farmers raise their incomes and standard of living. Because agriculture predominates in these areas, incorporating *Leucaena* into the farming system is one of the main goals of the Provincial Development Programme (Prussner 1981).

In 1980, Hawaiian Giant seeds were brought from Sikka to be planted in backyard gardens and alley cropped fields. In alley-cropped fields, these seeds were planted in straight double rows, 45 m apart, on the flat areas, and in single, contoured rows in hilly areas. In the hills, interrow spacings depend on slopes. Crop-yield trials using *Leucaena* as green manure were conducted at some of these locations and on farmers' fields.

The NTT Livestock Development Project aims to improve and stabilize farming systems in NTT through improved livestock management and stable cropping. A pilot project to determine the most appropriate technology is being conducted on 4 000 ha in south-central Timor by the Department of Animal Husbandry and the Australian Development Assistance Bureau.

The project began in March 1982. By January 1984, about 400 ha had been sown with contoured rows of *L. leucocephala* (cv. K-8, cv. K-28, cv. Cunningham), *Sesbania grandiflora*, *Macroptilium atropurpureum*, *Stylosanthes hamata*, *Stylosanthes scabra*, *Bothriochloa pertusa*, and *Chloris gayana* to demonstrate catchment stabilization and fodder production. Initial establishment was excellent.

Leucaena was also established in 1- to 3-ha demonstration areas at five locations in the four villages close to the project area to demonstrate stable cropping systems. Several research trials using *Leucaena* have been established. They investigate:

- the productivity of *Leucaena* (cv. K-8, cv. Cunningham, local) and *S. grandiflora* with and without phosphorous fertilizer,
- the nitrogen contribution of *Leucaena* and other crop/pasture rotation trials, and
- the best time of establishment of *Leucaena* and other pasture species, sowing methods, and seed treatments.

Once the appropriate technology is identified, the project will be extended to other areas within the district.

Initial results showed the following:

- giant varieties are more productive than the local variety;
- planting can be undertaken successfully months before the wet season;
- effective nodulation and establishment are encouraged by inoculation with soil from an established *Leucaena* field (Piggin and Parera 1984).

World Neighbors projects in East Sumba and in Ende (on the island of Flores) are attempting to improve water supply and agricultural production. They are particularly focusing on the dry district of East Sumba and the eroded, steep hills of southern Ende. The projects' goal is to stabilize the land and control erosion through the use of *Leucaena*.

On Sabu, a small, eroded, barren island halfway between Timor and Sumba, IRAE, a local organization, is introducing direct terraces with *Leucaena* hedgerows on small catchments. These have resulted in better maize and sorghum yields and have allowed the introduction of new crops such as onions, assorted vegetables, and lemon trees.

The Catholic Mission, either directly or in cooperation with the local government, is actively promoting the *lamtoronisasi* program in some districts. At Sikka, the Mission manages a Farmer's Training Institute at Waigete. The Institute trains young farmers from Sikka and other districts in dryland farming.

A large-scale *lamtoronisasi* program has existed in Ende since 1984. A large area of agricultural land was sown with *Leucaena* in the rainy season of 1984.

Lokomea, a small village in north central Timor, best illustrates the success of the giant *Leucaena* strain. Barren backyard gardens owned by smallholder families have been transformed into lush green areas following the introduction of *Leucaena*. Various crops such as papaya, bananas, pineapples, and vegetables can now be planted successfully. The *paronisasi* program in the area has already improved the villagers' income. About 50 ha of the surrounding agricultural land has been terraced with *Leucaena* hedgerows intercropped with pineapple and forage grass (planted on the lower side of the hedgerows). New crops such as pepper and cocoa are also being introduced.

Research issues and results

The question of whether to use cv. Hawaiian Bushy or Hawaiian Giant *Leucaena* to create indirect terraces needs more research. In Sikka, the bushy Hawaiian type is used for indirect terraces and fencing backyard gardens. The Hawaiian Giant is planted as a shade tree or in open fields and grassland as a source of forage and wood. The slower growing, shorter, cv. Hawaiian Bushy is preferred where climbing crops such as pepper and vanilla are grown. In some of the villages of the Provincial Development Programme and the World Neighbors projects, however, the giant types are preferred for indirect terraces. More frequent hedgerow pruning of the giant types (once in every 4 weeks compared with every 7 weeks for the bushy type) is evidently advantageous to the farmer, as it provides more browse to feed cattle.

For partial shading when food crops were planted, some farmers in Sikka girdled the trees of the giant strain by cutting off a 20 cm wide ring of bark from the tree 1.5 m above ground. This provides partial shading until the first weeding. This microclimate is beneficial for the early growth of some food crops (especially upland rice and maize). It helps the crops overcome extreme drought. New growth that emerges below the girdle is pruned to allow only a single sprout to form a new tree. The dead part of the tree above the girdle is then cut for fuel after the food crops are harvested. Some owners of small plantations of coffee and other perennial crops who used the giant type as a shade tree have benefited from the trees' windbreaking function. Sometimes, however, fallen branches and heavy concentration of raindrops can damage crops (Parera 1984a, b; NAS 1984).

The *paronisasi* program, which relies on a cut-and-carry system, does not support soil conservation: most of the cattle dung is left in backyard gardens. To take advantage of this manure, in 1985, the Provincial Development Programme began to construct simple, temporary stables in the field on one of the alley strips. In 1986, this alley strip, which had become more fertile, will be cultivated for food crops; stables will then be built on another alley strip (Parera 1985). This study also showed that *Leucaena* becomes well established when sown with maize; in this situation, maize yields are not reduced.

Conclusions

The successful introduction of *Leucaena* reflects its ability to adapt to the harsh and dry conditions of Nusa Tenggara Timur to meet the needs of local farmers. *Leucaena* improves soil conditions and the microclimate; improved agricultural techniques can then be introduced. The fast-growing Hawaiian Giant can also serve as a cash crop. The sale of *Leucaena* wood, leaves, and seeds has already provided good income for the farmers.

Despite these achievements, NTT still needs to do a lot more to improve the environment and quality of life through the use of woody species such as *Leucaena*. More research on the inclusion of other leguminous species in the system is required.

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Alley farming in Sierra Leone

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Abstract — This paper focuses on alley farming research activities at Njala University College in Sierra Leone. The objectives of, and data from, this research is summarized and information on some recent alley farming research is provided.

Introduction

Alley farming as an alternative to bush fallow would be welcome in Sierra Leone for the following reasons:

- Most of the primary forests have been lost as a result of shifting cultivation and the gathering of firewood.
- Fallow and cropping cycles have been shortened because of population and other pressures on agricultural land. The length of the fallow period is now 5–8 years and the cropping period is 2 years. This has led to declining soil fertility and crop yields on the uplands of Sierra Leone.
- There is a shortage of animal feed during the dry season (October/November–February/March). During this period, much of the grass dries out and cattle and small ruminants depend on poor-quality feed.

There is, therefore, justification for seeking an alternative, low-input system that can maintain soil fertility and crop yields for a relatively long time. Such a system should also provide forage for animals.

Although alley farming has great promise as an alternative to bush fallow, it is essential to test and identify adaptive, fast-growing leguminous species that should be used in the system. Usually, an indigenous species that does as well or better than exotic species is preferred.

This paper highlights recent research undertaken at Njala University College (NUC) in Sierra Leone. This research is considered a necessary prelude to any alley farming work in the country.

Research at NUC

Nitrogen-fixing trees

The nitrogen-fixing trees (NFT) research project was started in 1984 with funds provided by the International Development Research Centre (IDRC) and the University of Sierra Leone. The objective was to collect, propagate, and evaluate species to identify those that could be incorporated into bush fallow and other agroforestry systems in Sierra Leone.

A countrywide inventory of species has resulted in the collection and identification of 69 accessions comprising 19 species (Amara 1985a). Fourteen of these accessions have been propagated and established in evaluation trials on different soil types in northern, southern, and eastern Sierra Leone (Table 1). The best and most widely adapted species include *Albizia falcataria*, *Albizia lebbeck*, *Cassia alata*, *Cassia siamea*, *Delonix regia*, *Enterolobium cyclocarpum*, *Gliricidia sepium*, *Leucaena leucocephala* cv. K-8, and *L. leucocephala* cv. K-28.

Gliricidia evaluation

The *Gliricidia* evaluation is being coordinated by the International Livestock Centre for Africa (ILCA) and is funded by IDRC. This trial was established in June 1985 to identify species that could be used as dry-season browse and as a source of mulch in alley farming. After 8 months, results indicate that ILG 52, NLGO, HYP-bulk, and ILG 63 are the best performers (Amara 1985b). The alleys between the *Gliricidia* species will be planted with maize during the 1986 cropping season after the trees are harvested.

Leucaena–Gliricidia

Leucaena and *Gliricidia* are being cultivated continuously to test whether crop yields and soil fertility will be maintained for at least 5 years. The plots were established in June 1985 and the following treatments will begin in 1986:

- sole maize;
- *Leucaena* alley cropped with maize (no prunings returned);
- *Leucaena* alley cropped with maize (prunings returned);
- *Leucaena* alley cropped with maize (prunings returned + 0.25 N–P–K — one-quarter of the N–P–K recommended for maize);
- *Gliricidia* alley cropped with maize (no prunings returned);
- *Gliricidia* alley cropped with maize (prunings returned); and
- *Gliricidia* alley cropped with maize (prunings returned + 0.25 N–P–K)

Table 1. Nitrogen-fixing trees established for evaluation on different soil series in the northern, southern, and eastern Sierra Leone.

North (Tubum soil series)	South (Njala soil series)	East (Manowa soil series)
Acacia nilotica	*Acacia nilotica*	*Acacia nilotica*
A. senegal	*A. senegal*	*A. senegal*
Adenanthera pavonina	*Adenanthera pavonina*	*Adenanthera pavonina*
Albizia lebbeck	*Albizia falcataria*	*Albizia lebbeck*
Cassia siamea	*A. lebbeck*	*Cassia siamea*
Delonix regia	*Cassia alata*	*Delonix regia*
Enterolobium cyclocarpum	*C. siamea*	*Enterolobium cyclocarpum*
Gliricidia sepium (Ex IITA)	*Delonix regia*	*Gliricidia sepium* (Ex IITA)
G. sepium (local collection)	*Enterolobium cyclocarpum*	*G. sepium* (local collection)
Leucaena leucocephala cv. K-8	*Gliricidia sepium* (Ex IITA)	*Leucaena leucocephala* cv. K-8
L. leucocephala cv. K-28	*G. sepium* (local collection)	*L. leucocephala* cv. K-28
	Leucaena leucocephala cv. K-8	
	L. leucocephala cv. K-28	
	Sesbania grandiflora	

Other studies

Personnel at the Adaptive Crops Research and Extension (ACRE) project and the Oxford Forestry Institute in the UK have started other alley cropping studies. Work in Sierra Leone has so far concentrated on "setting the stage" for further alley farming work: i.e., identifying species that could be used. Now that this has been done, Sierra Leone scientists are ready to accept and test the alley farming technology.

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Alley cropping in Cameroon

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Abstract — The Cameroon Institute of Agronomic Research introduced alley cropping to lowland farmers of the high-rainfall forest zone in 1984. Preliminary results from the on-station trials show differences in growth rates between Leucaena *species and cultivars.*

Introduction

Crop production and agricultural productivity in the lowland, high rainfall forest zone of Cameroon are hampered by land-preparation difficulties, low soil fertility, and the high cost of fertilizers. To improve the crop yields of lowland farms, alley cropping was introduced in 1984 within the Farming Systems Programme of the Cameroon Institute of Agronomic Research. In the alley cropping target area, small farmers still practice slash-and-burn agriculture and mixed cropping (Atayi and Ndjeunga 1985). In this system, short cropping periods alternate with long fallow periods to restore soil fertility. During the fallow period, plant cover protects the soil from erosion, improves soil fertility, and reduces soil temperature and weed infestation (Nye and Greenland 1965).

Because farmers cannot afford expensive chemical fertilizers, it is necessary to develop low-input, soil-management technologies that can sustain crop production. One of these technologies is alley cropping. Because intercropping is another characteristic of lowland agriculture, it is important that intercropping studies are added to the alley cropping system.

The addition of nitrogen to the soil by woody, leguminous species is one of the major advantages of alley cropping. Kang et al. (1984) reported that 15 t of fresh *Leucaena* prunings annually provided 160 kg/ha N, 15 kg/ha P, and 150 kg K/ha to sandy Entisol of Nigeria. Guevarra et al. (1978) reported annual nitrogen fixation as high as 500 kg N/ha under favourable growing conditions in Hawaii. Rachie (1983) reports a nitrogen yield of 127 kg/ha for 4-month-old *Leucaena* plants grown in the Cauca Valley of Colombia. With alley cropping, farmers will be able to crop one portion of the land for many years. Consequently, less labour will be needed to clear the forest and to cut trees. Moreover, soil fertility can be maintained and improved; agricultural production and productivity in the area will, therefore, increase.

Study area and methods

Biophysical characteristics

The Cameroon Institute of Agronomic Research has divided Sierra Leone into three major environmental zones: highland; lowland, high-rainfall forest; and lowland, low rainfall. The lowland, high-rainfall forest zone is located between 2 and 5° N and 10 and 16° E. The main characteristic of the zone is the evergreen and semideciduous forest, which covers more than 60% of the arable land. Slash-and-burn agriculture and mixed cropping are practiced by almost all small farmers. The soils are acid, highly weathered Ultisols and Oxisols with low-activity clay and low nutrient reserves.

Four crops are always present in the field: cassava, groundnut, maize, and plantain. These crops are intercropped among themselves and with various vegetables. Sheep, goats, and chickens are raised in the area; cattle are not. Important cash crops are cocoa, coffee, and oil palms. Food crops are cultivated by women; men usually take care of cash crops. There are two cropping seasons: March–June and August–December. On-station trials were carried out in the high-rainfall forest zone in the Yaoundé area.

On-station stage

On-station research in alley cropping is projected to last 7 years (1982–1988). From 1982 to 1984, many leguminous tree seeds were imported from areas with the same environment as the Cameroonian lowlands. The seeds were planted and managed similarly. The most adapted legumes were *Leucaena leucocephala* cv. K-28 and cv. Cunningham and *Leucaena diversifolia*. Intercropping studies were conducted during the same period. Techniques to intercrop maize and groundnut, maize and cassava, and maize and cowpea or soybean were set up. In 1985, associated crops were planted in established alleys to evaluate the effects of *Leucaena* prunings on mixed crops. Soil and growth parameters will be studied. *Leucaena* seeds will be produced for distribution to selected farmers.

On-farm stage

The on-farm stage will last 3 years (1989–1991). The on-station package will be tried in selected farmers' fields. The reactions and behaviour of the farmers will be monitored. This feedback will help to modify the package to better fit farmers' conditions.

Extension stage

The extension phase will last at least 3 years. If the package is well accepted, it will be extended throughout the lowland, high-rainfall forest zone. By this time, it is hoped that other leguminous trees adapted to this zone will have been found.

Results and discussion

Of all the woody leguminous species tested between 1982 and 1984, only four showed promise. Seven months after planting, *L. diversifolia* was the tallest (>2 m), followed by *L. leucocephala* cv. Cunningham; cv. K-636 and cv. K-28 showed the least growth (<1.5 m). All *Leucaena* cultivars grew quickly during the first 3 months. The fastest growth rates were observed with *Leucaena diversifolia* and cv. Cunningham. Six months after planting, the growth rate was very low. *Leucaena diversifolia* gave the highest aboveground biomass yield 7 months after planting (>3 t). Cultivar K-636 gave the lowest yield (<2 t). There was no difference in biomass yields between cv. K-28 and cv. Cunningham (Fig. 1).

From these observations, it can be concluded that these cultivars of *Leucaena* have low to medium adaptation. This is probably due to soil acidity at the test site (pH < 5.0).

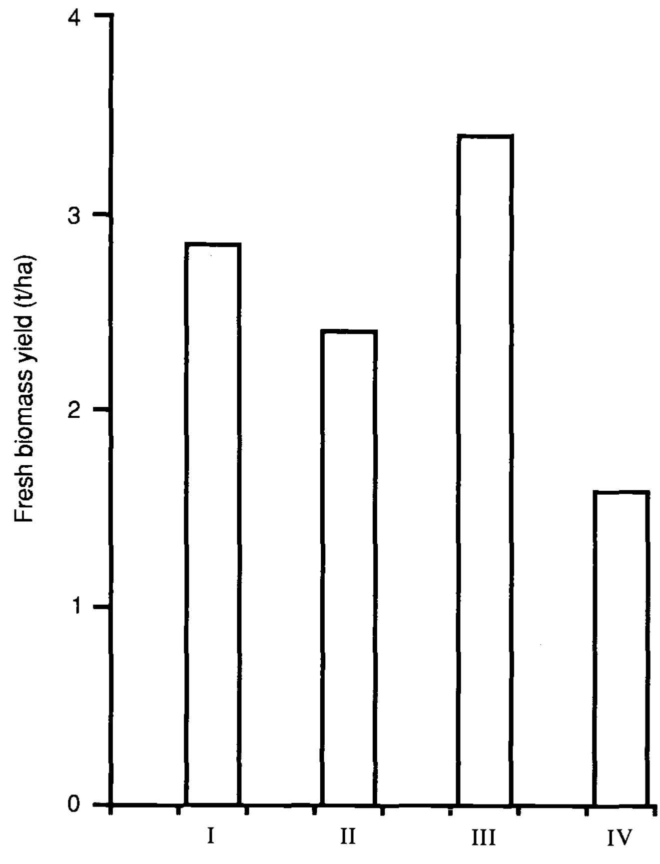

Fig. 1. Aboveground biomass yield of four varieties of *Leucaena* at Yaoundé (7 months after planting). I, *L. leucocephala* cv. Cunningham; II, *L. leucocephala* cv. K-28; III, *L. diversifolia*; IV, *L. leucocephala* cv. K-636.

Edea agroforestry experiment

From 1978 to 1982, an agroforestry trial was carried out at Edea in the Littoral Province of Cameroon (Maimo 1983). One objective of the experiment was the introduction of local and exotic leguminous tree species that could be used for various purposes by farmers in the forestry industry. Exotic seeds were introduced from similar agroecological zones abroad. Observations at 18 months after planting showed that only 3 of the 28 introduced species gave good growth: *Albizia falcataria*, *Albizia lebbeck*, and *Phithe colobium*. This agroforestry project lasted only 4 years and was discontinued.

In 1986, the trials at Yaoundé were intercropped with maize and groundnut and with maize and cassava. The effects of *Leucaena* prunings on the crops were evaluated.

Conclusion

Alley cropping retains the basic components of traditional bush fallow agriculture and introduces important improvements. This makes sustained and continuous cultivation of food crops possible. Biological recycling of nutrients, soil conservation, suppression of weeds, and reduced work load are major benefits of alley cropping for the farmers.

Alley cropping is still a very new technology in Cameroon. Preliminary observations have shown that *L. leucocephala* cv. K-28 and cv. Cunningham have a low to medium adaptability in the lowlands of Cameroon. Introduction and evaluation of new leguminous woody species are needed to identify more suitable materials for alley cropping on acidic soil. Because traditional farmers practice intercropping, more research in this area will also be conducted.

Acknowledgments

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Alley cropping in the coastal area of Kenya

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Abstract — On-station and on-farm trials were carried out using multipurpose or leguminous trees and shrubs. The research partly focused on testing these woody species for enhancement of crop and livestock feed production and improvement of soil fertility. This paper reports some of the results obtained with Leucaena, Sesbania, Casuarina, Gliricidia, *and* Acacia albida *in the coastal area of Kenya. Woody species established well in the coastal region. Maize intercropped with woody species in the 2nd and 3rd year showed low yields, particularly at higher tree densities. Prunings of* Leucaena *and* Gliricidia *hedgerows produced substantial amounts of biomass and nitrogen. In the 3rd year after establishment and following hedgerow prunings, maize alley cropped with* Leucaena *yielded more than the control plot. Tree establishment improved soil fertility and reduced weed infestation. In 3 years,* Leucaena *and* Casuarina *can produce 175 t/ha and 86 m³/ha of commercial wood, respectively.*

Introduction

The coastal area of Kenya is both ecologically and economically distinct from the rest of the country. Its rapid socioeconomic development and high population growth rate have resulted in high rates of environmental degradation because of increased food-crop farming and deforestation.

Annual rainfall is highly variable, ranging from 600 to over 2 000 mm. During the period of the experiment (1982–1985), annual rainfall ranged from 1 288 (1983) to 1 938 mm (1982). There are two short growing seasons: April–July and October–December.

Soils are generally highly leached and inherently infertile. The soils of the experimental site are sandy, acid, and low in organic matter, cation exchange capacity, and nutrient status. Maize yield in the area is generally low (900–1 000 kg/ha); nitrogen is required for good yields. Weeds are a major problem and can result in losses in crop yield. Weeding can occupy 40–50% of the farmers' time.

The combination of low soil fertility and weed problems suggests that alley cropping might be a more suitable land-use system for the coastal lowlands of Kenya. The tree component of this system would provide nutrients to the soil and diversified farm produce to farmers and the community (food, livestock feed, fuelwood, etc.).

Long-term agroforestry and alley cropping experiments were initiated in mid-1982. Selected tropical, multipurpose tree or shrub species (MPTs) were used. The experiments had the following objectives:

- to assess the performance of woody species in the coastal environment;
- to assess the interaction of MPTs on associated food crops when intercropped;
- to determine the fuelwood yield of woody species in the agroforestry system; and
- to assess the potential of agroforestry and alley cropping as a land use system.

Some of the results of these experiments from 1982 to 1985 are discussed here.

Experimental design

Several MPTs, including leguminous species, were screened and long-term research and demonstration plots were established. Species tested in the agroforestry and alley cropping experiments included *Gliricidia sepium*, *Leucaena leucocephala*, *Sesbania grandiflora*, *Acacia albida*, and *Casuarina equisetifolia*.

A parallel systematic design (Huxley 1983) with 2, 4, and 8 m between rows, 0.5, 1, 2, and 3 m within rows, and an east–west row orientation was used (Fig. 1). The MPTs were established with a cassava crop. Subsequently, maize was planted between the hedgerows during the long rainy seasons of 1983 and 1984. Because of canopy closure and severe competition from the hedgerows, hedgerow sides were pruned in 1984. In 1985, *Leucaena* and *Gliricidia* hedgerows were pruned before maize cropping, primarily to reduce shading. The planting density and crop husbandry practices recommended by the Ministry of Agriculture and Livestock Development were used. Maize was planted at a density of 90 × 30 cm (one maize plant per hill) (Muturi 1981). Fertilizer was applied to all plots at the rate of 36 kg N/ha (calcium ammonium citrate) and 44 kg P_2O_5/ha (triple superphosphate).

Results and discussion

MPT establishment

Cassava was used as the initial companion crop in May 1982 to establish woody species. It was harvested about 1 year later. The survival and growth rate of all species except *S. grandiflora* was good (Table 1). This was true even when trees and shrubs were intercropped with food crops. MPTs continued to perform well during this initial establishment phase.

At high and low densities, trees and shrubs grew equally well. Tree height is affected little by inter- and intrarow spacings (Table 2), especially during the first 3 years after establishment. Row width and line density have a significant effect on biomass yield: highest yields are attained with 2- and 4-m interrow and 0.5- and 1.0-m intrarow spacings. At these high density ranges, optimum biomass was

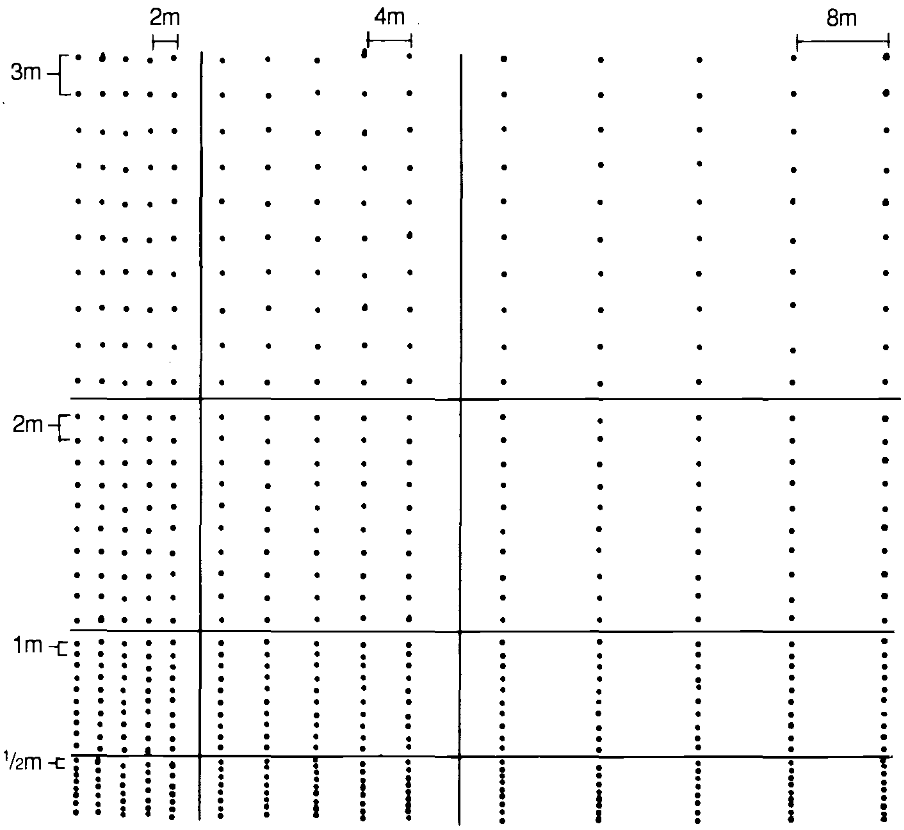

Fig. 1. Layout used in the research and demonstration plots.

reached at 26–30 months for *Casuarina*. Low density ranges (8-m interrow spacing) required longer cutting cycles. This situation results in high revenues from wood, particularly if it is sold for poles as was *Casuarina*. The increase in wood yield more than compensated for the decline in the 1984 crop yield (Table 3). Tree canopy closure was realized after 18 months with the 2-m interrow spacing and, to a lesser extent, with the 4-m interrow spacing. This resulted in less weed infestation.

Crop performance

Moisture stress and shading in the 2-m alleys and, to a lesser extent, the 4-m alleys became severe 1 year after establishment. This is evident from the effects of *Casuarina* on 1983, 1984, and 1985 maize yields (Table 3). The 1984 maize yield under *Casuarina* was particularly low compared with 1983 and 1985 because of the low rainfall in 1984 (Table 3). Maize yields for 1985 were lower than 1983 yields because of increased shading and competition from woody species.

Similar trends were observed with crops grown under *Gliricidia* and *Leucaena* (Tables 4 and 5). The low 1984 maize yields were aggravated by poor seasonal rains.

Table 1. Survival (%) and mean plant height (cm) after the 1st year of selected woody species established with cassava at Mtwapa, Kenya.

Species	Survival	Mean height
Acacia albida	72	144
Casuarina equisetifolia	99	251
Gliricidia sepium	82	288
Leucaena leucocephala cv. K-28	83	371
Sesbania grandiflora[a]	67	33

[a] Mostly from direct sowing because of low survival rate from seedlings.

Table 2. Plant heights (Ht, m) and breast-height (1.3 m) diameters (dbh, cm) of selected woody species in 2, 4, and 8 m wide alleys after 3.5 years at Mtwapa, Kenya.

	2 m		4 m		8 m		Average	
Species	Ht	dbh	Ht	dbh	Ht	dbh	Ht	dbh
Acacia albida	4.4	8.6	5.1	10.0	5.8	11.6	5.1	10.1
Casuarina equisetifolia	8.7	11.8	10.6	12.6	12.3	12.0	10.5	12.1
Gliricidia sepium	5.7	5.5	4.9	5.4	4.5	5.1	5.1	5.3

Table 3. Effect of *Casuarina* hedgerows on maize yield (kg/ha) during the first 3 years after establishment at Mtwapa, Kenya.

Intrarow spacing (m)	Interrow spacing 2 m			4 m			8 m		
	1983	1984	1985	1983	1984	1985	1983	1984	1985
0.5	350	180	250	2020	460	300	3000	1610	600
1.0	530	60	375	1430	325	250	2750	1038	413
2.0	1830	240	386	3870	625	275	3820	1088	413
3.0	1530	347	567	3900	625	300	2250	1084	533
Mean	1060	207	394	2805	509	281	2955	1205	490
Control (no trees)				3000	2750	2550			
District average				2500	1800	—			
Seasonal rainfall (mm)				1063	906	1174			

Note: Side trimming was done in September 1984 in the 2- and 4-m interrow spacings to reduce shading.

Table 4. Effect of *Gliricidia* hedgerows on maize yield (kg/ha) at Mtwapa, Kenya.

Intrarow spacing (m)	Interrow spacing 2 m		4 m		8 m	
	1984	1985	1984	1985	1984	1985
0.5	600	3000	380	2650	1798	1650
1.0	180	2400	190	2025	1020	1700
2.0	410	2478	860	2625	921	1425
3.0	243	1950	558	2167	1183	1450
Mean	358	2457	304	2367	1230	1556
Control (no trees)			2750	2526		
District average			1800	—		
Rainfall (mm)			906	1174		

Note: In 1984, hedgerows were under 2 years old and unpruned. During the 1985 cropping, hedgerows were pruned to a height of 10–15 cm.

Table 5. Effect of *Leucaena* hedgerows on maize yield (kg/ha) at Mtwapa, Kenya.

Intrarow spacing (m)	Interrow spacing 2 m		4 m		8 m	
	1984	1985	1984	1985	1984	1985
0.5	0	4000	90	3400	250	3100
1.0	0	3600	0	2675	205	2475
2.0	0	3600	15	2363	619	3100
3.0	16	2500	196	2683	107	2033
Mean	4	3425	75	2780	295	2677
Control (no trees)			2750	2526		
District average			1800	—		
Rainfall (mm)			906	1174		

Note: In 1984, hedgerows were under 2 years old and unpruned. During the 1985 cropping, hedgerows were pruned to a height of 10–15 cm.

Because of the dense canopy, *Leucaena* and *Gliricidia* hedgerows were cut back to single stems during the green gram crop season (September–December 1984). Despite the long dry season (December–March), there was good regrowth of the hedgerows. In mid-March 1985, 2 weeks before maize planting, *Leucaena* and *Gliricidia* hedgerows were cut back and subsequently pruned at intervals. This reduced shading on the associated maize crop and provided mulch and green manure.

Substantial amounts of biomass were obtained from these prunings (Table 6). They also yielded a substantial amount of nitrogen: from 48 kg N/ha with 8-m

Table 6. Fresh biomass yield (t/ha) of *Leucaena* hedgerows from three prunings, March–May 1985.

Intrarow spacing (m)	Interrow spacing			
	2 m	4 m	8 m	Mean
0.5	28.3	18.3	12.1	19.5
1.0	17.4	8.6	6.2	10.7
2.0	13.9	6.5	4.6	8.3
3.0	11.3	8.2	4.8	8.1
Mean	17.7	10.4	6.9	11.7

interrow and 3-m intrarow spacings to over 280 kg N/ha for 2-m interrow and 0.5-m intrarow spacings.

When alley cropped with *Leucaena* or *Gliricidia*, maize yields increase (Tables 4 and 5). This is because of soil enrichment by woody legumes and the addition of the prunings (Table 6). Yields of the alley-cropped maize in 1985 also showed a significant interaction (at 5% level) with increasing inter- and intrarow hedgerow spacings (Table 5).

Weed infestation

The plots gradually became less infested with weeds during the period of tree-establishment. As the hedgerow canopy closed at about maize harvest time, particularly with the 2- and 4-m interrow spacings, weeds disappeared. As weeds disappear, the amount of labour devoted to weeding decreased.

Weed infestation in the alley plots was significantly lower during the dry season between the cropping seasons than in the control plot (no trees). In the *Leucaena* alleys, most of the weeds were broad-leaved species. Compared with the grasses and sedges (nut grass) in the control plot, these species are easily removed.

Soil properties

The nutrient status of the surface soil distinctly improved in the alley cropped plots compared with the control plots. Soil pH also increased over time in the alley cropped plots. The nutrient status (N, P, K, Ca, Mg) of the soil also increased with an increase in tree density. The 2-m interrow spacing showed the highest nutrient levels.

Financial returns

All woody species, except *S. grandiflora*, showed high wood yields and associated fresh and green biomass yields. The wood represents an important source of income and a much-needed product for both rural and urban populations. Its yield eclipsed the decline in crop yields during the 2nd and 3rd years. The annual net income from the wood of *Casuarina* (used mainly for construction

Table 7. Annual net farm income (KES/ha)[a] from a 3-year-old *Casuarina* food crop agroforestry system at Mtwapa, Kenya.

Intrarow spacing (m)	Interrow spacing 2 m	4 m	8 m
0.5	44000	26000	16000
1.0	27700	14300	9000
2.0	15700	9000	5700
3.0	10300	6700	3300
Control (agriculture only)		7300	
Forestry control		2000	

[a] In November 1988, 16.9 Kenyan shillings (KES) = 1 United States dollar (USD).

poles) under an agroforestry system compared with forestry and agriculture showed that an agroforestry system is more productive than crop farming alone (Table 7).

Conclusions

A tree-based land-use system, particularly an agroforestry system, appears to be a suitable system for the tropical coastal lowlands of Kenya. The system can effectively overcome environmental constraints such as poor soils and weed infestation. It can exploit more effectively the positive features of the environment (i.e., radiation, temperature, and rainfall). Growing trees in an agroforestry system is usually effective because crop husbandry (land preparation, weeding, fertilization, etc.) greatly benefits the woody species.

High tree densities (2 500–10 000 trees/ha) result in better weed suppression, improved soil fertility, and shorter wood-harvesting cycles. With leguminous woody species such as *Leucaena* and *Gliricidia*, which are destined for alley cropping, a deep and extensive root system is established. Consequently, woody species are better able to withstand periodic pruning. Therefore, the first pruning should occur at least 18 months after planting.

Unpruned trees severely depress maize yield because of shading. When *Leucaena* was pruned to reduce light competition and the foliage was used for mulch, higher maize yields compared with the control plots were realized at the higher interrow and intrarow densities of *Leucaena*.

Acknowledgments

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Part 6

Socioeconomic and Ecological Considerations

Role of multipurpose trees in compound farming in tropical Africa

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Abstract—The home garden is an integral component of traditional farming systems in the humid and subhumid areas of tropical Africa. It is usually the operational base for several field systems in African agriculture. Species diversity and the complexity of the system is highest in the tropical forest zone and lowest in the savanna areas. The home garden is of major importance in the life-support system of rural communities. It supplies many products and contributes considerably to maintaining environmental quality and soil conservation. Components of the home garden ensure the year-round availability of different foodstuffs. A regular supply is assured through frequent harvest; storage and preservation are not required. It is therefore recommended that in finding solutions to the African food crisis, research on home gardens should be given high priority. Studies should be done on species composition and structure, nutritional roles, economic relevance, and overall ethnobotanical importance. Only through an understanding of the importance and role of home gardens in farming systems can programs to improve them and efforts in germ-plasm preservation be successful.

Introduction

The home garden or compound farm may be regarded as "a system of agricultural production largely conducted by the household members at or near their residence" (Brownrigg 1985). Brownrigg (1985) also defines home garden as "a supplementary food production system by and for members of a group of people with rights to the land, who eat meals together regularly." In this paper, a home garden in Africa is defined as a specialized agricultural production or farming system within the homestead area, usually surrounding the home of its operators. It usually constitutes one of a set of fields operated by a farmer or farm family. On these fields, one or more family members work all or part of the time to produce food and other products for subsistence, sale, or other purposes (Okigbo 1985).

The home garden is also called the backyard garden, kitchen garden, dooryard garden, compound farm, compound garden, or homestead garden. It varies considerably in size, shape, and intensity and complexity of cultivation. According to White and Gleave (1971), the compound kitchen garden is the most common permanent, traditional production system in tropical Africa. It is located close to the settlement and provides items frequently used in small quantities for relishes and sauces. It also produces crops that require guarding, more fertile soils, or individual attention.

The home garden usually contains tree crops, shrubs, arable crops, vegetables, ornamentals, and multipurpose species. It is often integrated in varying degrees with animal production and supplements other field systems operated by the same farmer or the farmer's family.

Plants featured in home gardens usually have several purposes. Multipurpose plants are plants that are kept and managed for economical or ecological reasons in any land-use system, especially agroforestry systems (Burley and von Carlowitz 1984). Multipurpose species may include herbs, lianas, shrubs, or trees. Most herbaceous species found in compound gardens have edible parts and are mainly used as food or condiments. This paper reviews the uses of the most common or frequently used ligneous species in the humid, subhumid and drier (savanna) areas of tropical Africa; most examples are taken from West Africa.

Evolution and development of home gardens

After several millennia of trial and error with plants and animals, agricultural production evolved into a slash-and-burn, shifting-cultivation system. This involved rearing animals and planting less weedy species such as cereals and other annual, largely herbaceous species. Agriculture was then migratory and farmers lived in temporary campsites. According to Burkill (1962), the most probable sequence of plant domestication involved cereals (probably the earliest to be domesticated); pulses or grain legumes; oil seeds; roots and tubers; herbaceous fruits; fibre and dye plants; and woody fruit trees and shrubs.

Burkill (1962) regarded perennials as the most intractable of plants, especially if they are tall trees. It is, therefore, likely that primitive nomads initially camped close to areas rich in trees and shrubs with edible fruits, nuts, seeds, and other plant parts, or in abandoned campsites with groves of edible trees and shrubs. These species must have been only seasonally exploited, when the edible parts were most abundant. Even if the seeds of these species were observed to germinate and produce seedlings, it is likely that nomads increased the frequency of camping near such groves or established protective sanctions over them. Progress in plant domestication resulted in the reliance on a few arable species as regular sources of food; a sedentary culture and permanent settlement evolved. The homestead garden or compound farm constitutes an agroecosystem formed at the site of a permanent settlement.

In contrast, Porteres (1962) maintains that after several centuries of hunting and gathering, and trial and error, two agricultural complexes evolved: one based on seeds and the other on vegetatively propagated plants. The seed-agricultural complex is characteristic of the savanna; it involves growing cereals and grain legumes in open fields. The vegecultural complex, characteristic of the tropical forest zone, involves the growing of vegetatively propagated plants, roots and tubers, fruit trees, and vegetables in gardens rather than in open fields. Whichever hypothesis is applied to the origin of home gardens, it is speculated that they are of relatively recent origin with the domestication and growing of arable crops such as yams, sorghum, and vegetables.

The homestead and its associated garden is the operational base for all the other cropped and fallow fields at different distances from the home garden (Figs 1 and 2). According to Okigbo (1985), the development of the home garden as a regular feature of the traditional farming system is, by and large, a result of the following four factors:

- Labour is divided by sex. Women, along with other responsibilities, cook the soups and sauces with which the major starchy staples (often produced by the men or the farm family) are eaten. Thus, the women grow several condiment plants, spices, and vegetables in the home garden to ensure a regular, year-round supply of fresh materials close to the kitchen. This proximity to the kitchen facilitates the tending of the crops and eliminates or minimizes the need for storage.
- A sedentary culture ensures that homesteads are located in places where edible and equally useful perennial plant species are abundant. With frequent slashing, burning, and clearing of vegetation, the development of the home garden ensures that several semiwild and wild species of edible trees and

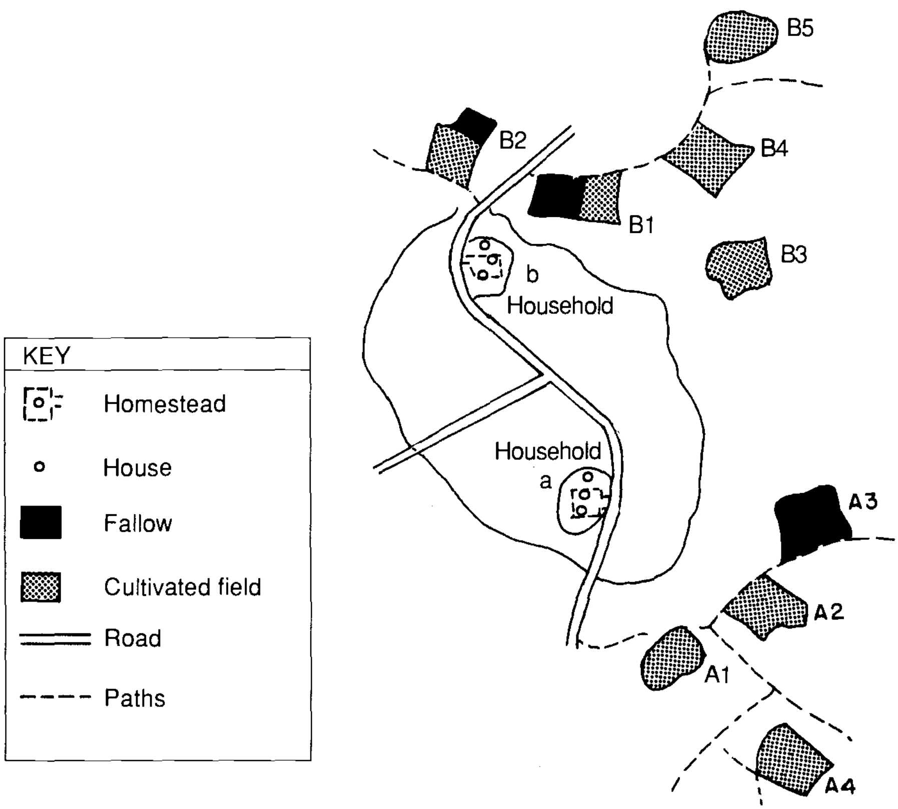

Fig. 1. Homestead fields and compounds in traditional farming systems in the humid tropics of West Africa: a, compound farm inside outer walls; b, compound farm outside compound fence or wall; A1, A2, B1, B2, near fields; A3, A4, B3, B4, distant fields (source: Okigbo 1984).

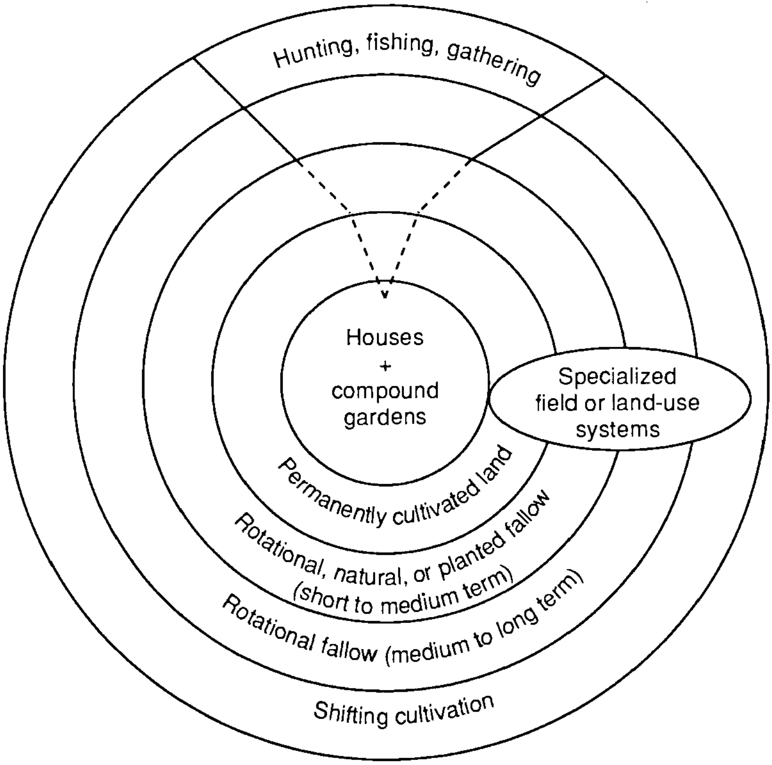

Fig. 2. The spatial organization of fields and farming systems in tropical Africa (source: Okigbo 1983).

shrubs that are gradually disappearing from fallow areas are grown and preserved close to residential areas.

- The home garden functions as an experimental area for interesting and useful plants collected during trips to neighbouring compounds, villages, towns, and far-away places.
- Home gardens provide rural farmers with the opportunity to realize the many uses of plants: food, feed, environmental protection, landscaping, or raw materials for crafts.

Structure and complexity

The diversity and complexity of home gardens depend on the climatic or ecological zones in which they exist. Species diversity is greatest in the humid tropics and lowest in the savanna areas (Table 1). This parallels the situation with natural vegetation. Human population density must be considered when examining species diversity. In the humid tropics, the structure of home gardens approaches that of a tropical rain forest in its multistoried structure and number of species. It is

Table 1. Number of food crops and useful plants encountered in home gardens in three ecological zones in Nigeria.

Crop group	Humid tropics (oil palm bush)[a] MH	H	Humid tropics (derived savanna transition zone)	Subhumid tropics (southern Guinea savanna)
Cereals	0–4	2–3	0–3	2
Roots and tubers, plantain	3–8	7–10	1–12	0–4
Legumes and pulses	0–3	0–3	1–5	3–5
Leaf vegetables	2–8	10–11	3–7	3–8
Fruit vegetables	0–6	3–4	4–6	4–6
Fruits, nuts, and oil plants	2–15	5–12	1–14	1–9
Spices and condiments	0–9	1–7	0–3	0–4
Miscellaneous useful plants	1–29	4–18	0–7	1–14

Source: Okigbo and Greenland (1976); Diehl (1982).
[a] MH, medium-high human population density; H, high human population density.

more or less a four-storied structure. The ground layer consists of crops such as sweet potato (*Ipomoea batatas*), early okra (*Abelmoschus esculentus*), melon (*Colocynthis vulgaris*), chili peppers (*Capsicum frutescens* and *C. annum*), meleguetta pepper (*Aframomum meleguetta*), or cocoyams (*Xanthosoma sagittifolium* and *Colocasia esculenta*). The second layer consists of shrubs such as citrus (*Citrus* spp.), bananas and plantains (*Musa* spp.), late okra, the soursop (*Annona muricata*), horseradish (*Moringa oleifera, Dennettia tripetala*), papaya (*Carica papaya*), croton (*Cordiaeum* spp.), *Afzelia bella* var. *bella*, *Newbouldia laevis*, the tree gourd (*Crescenta cujete*), the fever plant (*Ocimum viride*), pigeon pea (*Cajanus cajan*), or bitterleaf (*Vernonia amygdalina*). The third layer consists of taller trees such as the star apple (*Chrysophyllum albidum*), African pear (*Dacryodes edulis*), African breadfruit (*Treculia africana*), cola nut tree (*Cola* spp.), mango (*Mangifera indica*), oil palm (*Elaeis guineensis*), coconut palm (*Cocos nucifera*), guinea pepper (*Xylopia aethiopica*), oil bean (*Pentaclethra macrophylla*), or camwood tree (*Pterocarpus* spp.). The topmost or fourth layer contains trees that may also appear in the third layer: the African elemi (*Canarium schweinfurthii*), coconut palm, silk cotton (*Ceiba pentandra, Bombax buanopezence, Brachystegia* spp.), or the iroko tree (*Chlorophora excelsa*). As in the tropical rainforest, there are lianas and climbers that use these trees and shrubs for support: conophor (*Tetracarpedium conophorum*), rubber vine (*Landolphia owariensis*), *Gongronema latifolium*, dye plants (*Rothmannia* spp.), yams (*Dioscorea cayenensis, D. alata, D. dumetorum*, and *D. rotundata*), fluted pumpkin (*Telfairia occidentalis*), and arrow poison (*Strophanthus* spp.).

In southeastern Nigeria, the number of species in a home garden range from 18 to 62 (Lagemann 1977). Compound farm ecosystems of such structure and species diversity are also found in Zaire, the Kumasi area of Ghana, parts of the Republic of Congo, Uganda, and southern Cameroon.

In the Guinea and Sudan savanna areas of Nigeria, a more open, three-storied structure of less diversity may be encountered. In the Guinea savanna or "Middle Belt" of Nigeria, the ground or herb layer may consist of sweet potato, tobacco

(*Nicotiana tabacum*), roselle (*Hibiscus sabdarrifa*), bitter melon (*Cucumis* and *Colocynthis* spp.), or sesame (*Sesamum indicum*). The second layer may consist of shrubs such as henna (*Lawsonia* spp.), papaya, boundary plants of the *Euphorbia* spp. and *Newbouldia leavis*, citrus trees, the tree gourd, kenaf (*Hibiscus cannabinus*), or late okra. The tree layer is occupied by mango, African elemi, locust bean (*Parkia clappertoniana*), and date palm (*Phoenix dactylifera*).

In the Sudan savanna, the number of species in a home garden rarely exceeds 30. The dominant trees are the shea butter (*Butyrospermum paradoxum*), the baobab (*Adansonia digitata*), locust bean (*Parkia bigloba*), and the neem tree (*Azadiracta* spp.).

Uses of trees

Compound gardens contribute in many ways to the quality of life of small-scale farmers. Lagemann (1977) estimated earnings from compound gardens relative to returns from other farming systems in eastern Nigeria (Table 2). Some crops, like the colas, are of immense cultural and religious importance. Trees and shrubs in compound gardens are involved in nutrient recycling. There are more than 120 species of trees, shrubs, and lianas used in the humid tropics (Okafor 1981b). In surveys of home gardens in southeastern Nigeria, Walker (1985) reported 138 species; 35% were herbaceous, 65% were woody species.

Surveys in various parts of tropical Africa indicate that the ligneous trees, shrubs, and lianas in home gardens are used for food (vegetables, fruits, nuts, seeds, nectar, beverages, condiments); feed or fodder; medicine; furniture; structural materials (roofing, thatching, walling, beams, pillars); fuelwood; ornamentals; body decorations; hedging or fencing; fishing; musical instruments; ladders and climbing ropes; trellises and stakes; religious artefacts and traditional costumes, including

Table 2. Average value (NGN)[a] of crop production on compounds, outer fields, and fallow land in three villages of eastern Nigeria, 1974 and 1975.

Village[b]	Crops	Compounds	Outer fields	Fallow	Total
Okwe (L)	Arable	NA	265	5	270
	Tree	NA	4	165	169
	Total	NA	269	170	439
Umuokile (M)	Arable	64	80	2	146
	Tree	28	6	103	137
	Total	92	86	105	283
Owerre-Ebeiri (H)	Arable	70	44	2	116
	Tree	29	26	43	98
	Total	99	70	45	214

Note: NA, not available.
Source: Lagemann (1977).
[a] In September 1989, 7.3 Nigerian naira (NGN) = 1 United States dollar.
[b] L, low human population density; M, medium human population density; H, high human population density.

protective charms; handicrafts (baskets, mats, cordage); and farm implements (digging sticks, tool handles, cooking utensils, and containers). This paper will only consider the first two (human and animal feed).

Human food

Several ligneous species encountered in home or compound gardens are sources of food and flavouring substances. These include fruits, leaves, seeds, nuts, barks, and other plant parts. Fruit trees include mango, citrus, bananas and plantains, oil palm fruits, soursop and sweetsop, and African pear. Trees and shrubs producing edible nuts include the coconut and the oil palm. The liana conophor produces a seed that is high in protein and oil content. The bignoniaceus shrub produces bell-shaped flowers, the nectar of which is cherished by children. Both raffia palm and the oil palm are sources of palm wine, a popular alcoholic beverage that is high in B-complex vitamins. Several perennial shrubs and trees are good sources of leafy vegetables; some produce edible leaf flushes in the dry season (e.g., camwood, *Afzelia bella* var. *bella*, and horseradish).

Animal feed

Many trees and shrubs are specially grown in home gardens as browse or fodder plants although they have other uses. Several species of *Ficus* and *Ricinodendron heudelotii* are often grown for their leaves, which are fed to sheep and goats. The African breadfruit produces fruits that are cherished by goats after the seeds have been removed. Sheep and goats also relish the seeds of the African pear. Most trees and shrubs grown in home gardens yield by-products that are fed to penned animals.

Potential of multipurpose trees and shrubs

Until recently, the compound farm or home garden has been neglected as a target for improvement in agricultural research. This is in spite of the fact that it lends stability to the traditional farm environment and ensures the sustained production and income of the traditional low-resource farmer. Some of the trees and shrubs in home gardens fulfill strategic nutritional roles, in addition to contributing significantly to the farmer's income (Fig. 3), especially near urban centres, where the demand for fruits and nuts are high.

Home gardens also preserve the environment through soil conservation. In addition to being a rich reservoir of germ plasm of plants that may be valuable in industries based on renewable resources, they beautify the environment. There are many ways in which trees and shrubs in home gardens can be used to develop self-sustaining agricultural production systems, especially in the humid and subhumid tropics.

Germ-plasm collection and preservation

Many indigenous trees and shrubs of economic and nutritional importance (e.g., the African pear, *Dennethia tripetala*, conophor, the locust bean, shea butter, and the baobab) are found in home gardens or close to human habitation. Some of the traits of these species are often either obscured by dominant genes under natural conditions or are not easily accessible for observation, detection, and isolation. Therefore, priority should be given to the study of economically important plants found in home gardens. Various specimens should be described and documented and germ plasm should be collected and conserved.

Recent studies of compound gardens in Imo and Anambra states have identified *Cola pachycarpa*, *C. lepidota*, *Coaila edulis*, *Lascanthera africana*, and *Tetracarpedium conophorum* as rare or endangered species (Walker 1985). Studies by Okafor (1975, 1981a, b) have shown that variation exists: two forms have been identified in *Irvingia gabonensis* (var. *gabonensis* and var. *excelsa*), and in African breadfruit (var. *africana* and var. *inversa*).

These studies demonstrated the differences in economic importance of the various types and confirmed that compound garden species are amenable to conventional methods of horticultural propagation. There is no doubt that usual plant breeding methods and biotechnologies such as tissue culture can be used to enhance their potential.

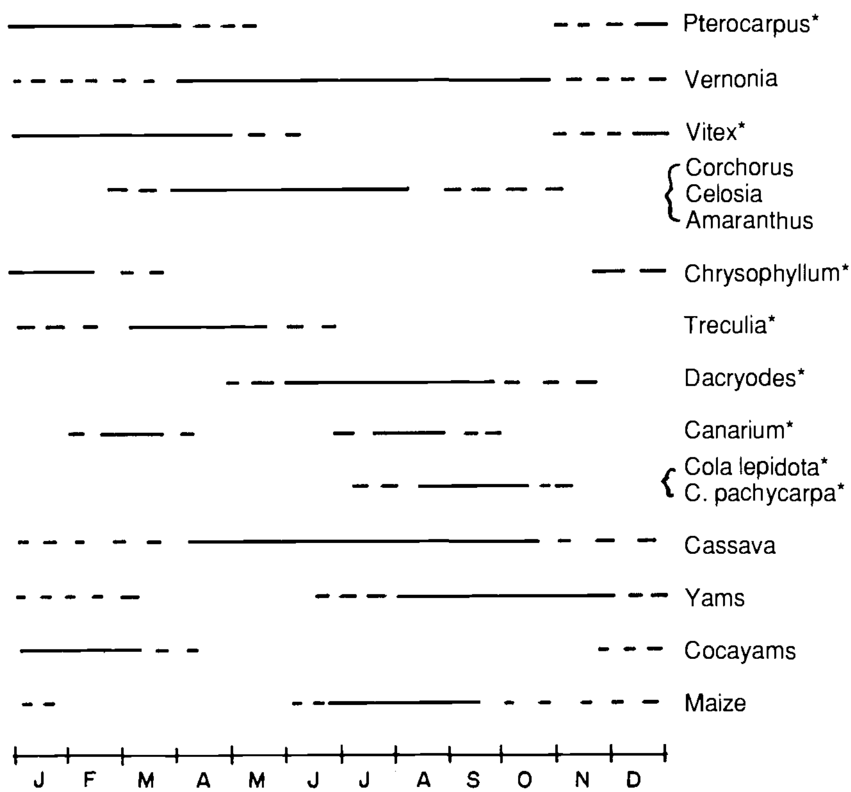

Fig. 3. Home gardens provide food and income throughout the year. Broken lines represent minor harvest periods or food being consumed from storage. Solid lines represent major harvest periods. *, tree crops (source: Lagemann 1977).

Improved cropping patterns

Certain sustainable farming systems (e.g., crop/livestock integration, coconut/pasture, coconut/cocoa, plantain/cocoyam, coffee/banana, and kolanut/*Marantochloa*) are ecologically stable and economically viable, involving compatible species in a structure of two or more stories. Studying plant interactions in home gardens will promote the modeling and subsequent improvement of such mixtures. Home gardens could also be used to design improved agrosystems involving trees and shrubs with animals or low-growing perennials.

Widening the spectrum of horticultural crops

Okafor (1981a) has demonstrated the potential of selection and propagation in the management, breeding, and genetic improvement of several indigenous, ligneous species in home gardens. As with mangoes and cashew nuts, fruit trees such as the velvet bean can be improved and regularly cultivated. Some of the fruits can be used in jams or preserves.

In some parts of southeastern Nigeria, some species of the camwood tree are sources of dry-season, leaf vegetables that are as good as or better than *Amaranthus* spp. and *Celosia argentia*. Improved methods of pruning will ensure better accessibility to this crop.

Industrial crops

Some trees and shrubs found in home gardens could be improved and put to industrial use. The fruit and seeds of the African pear, African elemi, oil bean, conophor, and African breadfruit contain more than 10% ether-extractable fat. Arils of the velvet tamarind are known to be high in vitamin C. The industrial potential of these species should be more seriously investigated. Growing such crops in plantations would provide rural employment. Because they are renewable resources, this would also lessen the need for imported raw materials.

Horticulture and landscaping

Where homesteads are scattered, compound gardens form a unique landscape — a forest of selected useful species. In fact, in areas of high population density and no urbanization, as in parts of southeastern Nigeria, it is difficult to tell where one village ends and another begins. There are individual ligneous species in home gardens that, in addition to their traditional uses, are good ornamental plants.

Conclusions

Home or compound gardens should be given greater priority in efforts to improve traditional farming systems because they involve multipurpose species. It is only by studying their structure, nutritional importance, economic importance, ethnobotanical value, and various uses that component species can be improved and used more effectively. Such research should include gardens in urban areas;

efforts aimed at their improvement should also focus on the utilization of indigenous species. Wherever possible, more exotics could be officially introduced to increase species diversity. The highest priority should be given to improving home gardens and broadening the food base of both the rural and urban poor.

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Land tenure systems and the adoption of alley farming

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Abstract — Alley farming is an agroforestry technology that requires access to land and the right to plant, own, and use trees. This paper considers the implications of land-tenure systems in southwest and southeast Nigeria for the acceptability and viability of alley farming. Considerable variation in the rules governing the use and control of land exists within and between the two regions, and any tenure system may include many categories of land to which different patterns of use and tenure apply. Broadly speaking, tenants in parts of southwest Nigeria may be disadvantaged, as their rights over rented land do not necessarily include the right to plant trees. In the southeast, communal systems of land ownership and management exist on some categories of land. This undermines both the ability to plant trees and the incentive to invest labour in the maintenance of soil fertility.

Introduction

Agronomically, ecologically, and economically, the case for alley farming is compelling (Kang et al. 1981; Hoekstra 1982; Sumberg et al. 1985; Reynolds and Adeoye, this volume). If alley farming is to have a significant impact on land-use patterns, however, it must be widely adopted by the resource-poor farmers who make up the vast majority of the farming population. This paper considers the implications of southern Nigerian land-tenure systems for the adoption of alley farming.

A land-tenure system is the body of rights and duties that regulates the use and control of land. Most African customary property systems distinguish between trees and the land on which they are planted. Rights to the one may be held and transferred independently of rights to the other. Thus, parallel and distinct systems of land and tree tenure may exist. However, because trees are, for practical purposes, attached to the land on which they stand, the two systems are not entirely separate. Planting trees obviously has long-term implications for the use of land, and those whose rights in land are temporary may be debarred from establishing permanent crops. Once planted, however, trees are generally considered the property of the planter. In some circumstances, therefore, tree planting may increase the security of rights to land.

Land-tenure systems govern a multiplicity of land uses and may be extremely complex. It is necessary to distinguish the land and tree rights that are necessary to practice alley farming. First, the prospective alley farmer with the right to plant trees on a certain piece of land requires access to this land. Second, rights over these trees must be sufficiently secure to justify the planting effort. Third, the farmer's right to harvest and use the trees' foliage must be exclusive enough to ensure an adequate return on investment. Fourth, rights to plant arable crops on the land where the trees are established must be of sufficient duration and security to enable the farmer to benefit from the system's ability to maintain or improve soil fertility.

The land rights that any person holds depend on the means by which access to that land was obtained (inheritance, purchase, loan, lease, or pledge). Thus, the implications of adopting alley farming for tenants, strangers, and pledges may differ from those for landowners and indigenes. Furthermore, status within the household may determine rights over land and trees. The rights of men may differ from those of women; the rights of household heads may differ from those of other household members; and the rights of the first-born child may differ from those of the other children.

Planting tree crops is scarcely an innovation in southern Nigeria, which has been a major producer of cocoa, kola, and palm products. However, the cultivation of these trees does not involve the intercropping and simultaneous management of trees and arable crops. Thus, the simultaneous exercise of rights over both the tree (the right to use its foliage), and the land on which it is established (the right to plant crops) has also been unknown. Furthermore, alley-farmed trees have multiple uses and, hence, there are many possible beneficiaries. Most of their products, however, are intermediate and have no market value.

Mulching will benefit the present cultivator, the future cultivator, or the landowner, depending on the system of land tenure. Cutting for livestock will benefit stockowners in the household; this group may include people who are not owners of the alley farm. Cutting for firewood will tend to benefit those (generally female) members of the household whose responsibility it is to provide firewood. There is, thus, no precedent in the institutions of tenancy to regulate the use of land for economic trees. There is also no precedent for the pattern of distribution of benefits between such parties.

This paper considers the implications of land-tenure systems for the acceptance of alley farming in southwest and southeast Nigeria. In each case, a general review of the region's tenure system, which draws mainly on secondary sources, is followed by case studies of the communities where the Humid Zone Programme of the International Livestock Centre for Africa (ILCA) has been conducting on-farm trials of alley farming (Fig. 1). The case studies consist of brief accounts of the communities' social constitutions and farming systems and an outline of the relevant features of the local land-tenure system. The way in which the opportunities and constraints presented by these systems have shaped the adoption and use of the browse trees by farmers is then considered. A final section considers the general implications of these findings.

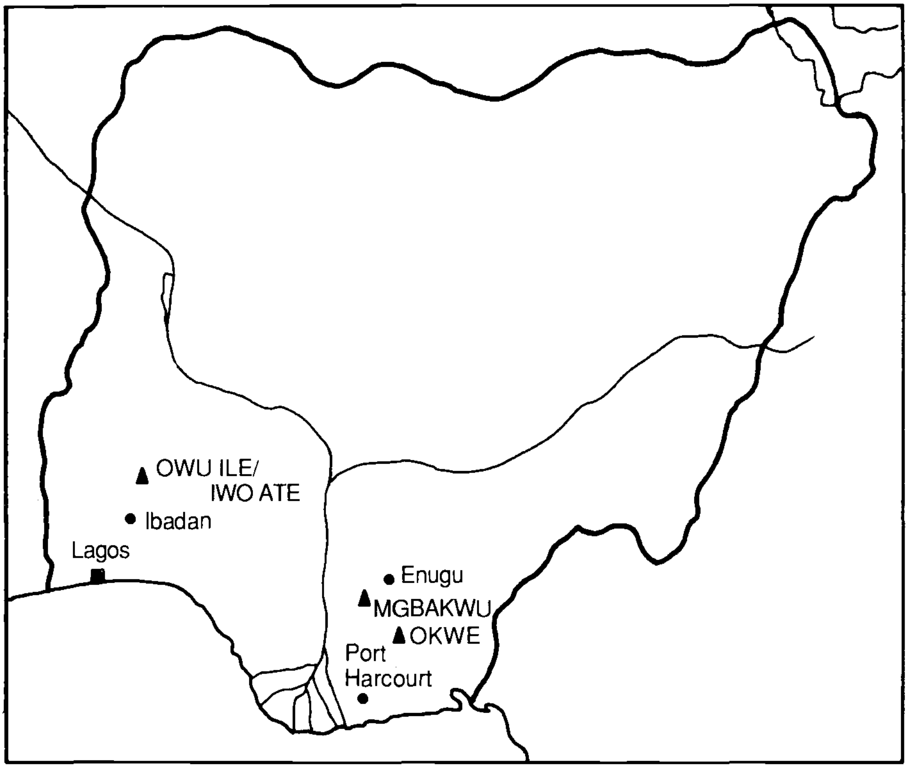

Fig. 1. Communities in which the International Livestock Centre for Africa (ILCA) has conducted on-farm trials in Nigeria (▲).

Southwest Nigeria

General features

Land-tenure systems in southwest Nigeria show marked regional variation. Under the influence of increasing population densities and the spread of cocoa cultivation in this century, land-tenure systems have also been subject to considerable change.

Rights over land may be vested in a variety of social groups. These groups may be defined in political, residential, or kinship terms, or a combination of these. In most areas, the important unit of land ownership is lineage. Criteria for lineage membership are by no means uniform; in particular, recognition of the validity of nutritional links (i.e., "the mother's side") is variable. In general, there is a fairly strong patrilineal ideology; in practice, however, kinship links of other kinds, as well as coresidence, may form the basis for participation in lineage affairs and access to land. Lloyd (1962) recorded that lineage land in some areas was reallocated annually to members and, elsewhere, lineage members required the permission of the lineage to plant permanent crops. In general, however, whether land is obtained through membership of a community or lineage or through inheritance, the wider group exercises little control over its use and the individual is free to plant either food or tree crops.

Nonmembers of landowning groups may also obtain the use of land. Within the traditional system, granting land to immigrants was merely an aspect of their integration into the community. Where tribute was paid, this was a question of political, rather than economic, significance. As scarcity has given land a value, relations between the grantors and grantees of land have become more narrowly economic, although the process has been an uneven one. "Strangers" may obtain access to land in many ways. Most critical for the purposes of this discussion is the fact that grants of land do not necessarily include the right to plant trees (Galletti et al. 1956; Francis 1984).

These restrictions notwithstanding, outsiders have been able to obtain land from landowning groups for the cultivation of economic trees. The terms of such arrangements vary from place to place. In general, an initial payment was made when the land was granted and this was followed by annual payments to the landowner in cash or kind. These payments came to be known as *isakole* and were enforceable in customary courts. Over the years, the social obligations and implications of tenancy have tended to diminish; at the same time, the cost of obtaining land rights has risen.

Cocoa farms, like other improvements on the land, are considered the property of the planter rather than the landowner. In most areas, tenants have the right to rent, pledge, or otherwise use the cocoa trees as security for loans; they may also bequeath the trees to their heirs. Tenants are also usually allowed to sell their trees. Berry (1975) reports, however, that landowners in Ibadan are reluctant to allow such transactions, possibly for fear of the new owners laying claim to the land itself.

Allocations of farmland, either to members of landowning groups or to tenants, do not include the right to exploit economic trees already on the land, whether they were self-sown or planted by a previous occupant. The right to reap palm trees, in particular, implies rights of ownership; thus, disputes about palm trees are often disputes about land. In general, firewood may be collected freely, although one may not enter another's cultivated farm for this purpose.

Owu Ile and Iwo Ate

The adjacent settlements of Owu Ile and Iwo Ate are situated some 22 km northeast of Oyo on the road to Ejigbo in Oyo State. They lie in the transitional zone between forest and savanna and many of the inhabitants have farms in both ecological environments. Soils are mainly Alfisols and Entisols. Annual rainfall averages 1700 mm. The two villages consist of some 172 households with an average of 3.6 adults per household (Okali and Cassaday 1985). Agriculture is the principal occupation for men. Women frequently farm independently of their husbands and, in general, are engaged in gainful activities such as food processing and petty trading in addition to their domestic responsibilities. Typically, farms consist of a cultivated area of 1 or 2 ha scattered over many holdings. Farms are situated up to 4 km from the villages. No cultivation takes place in the villages themselves and livestock are allowed to roam unrestricted. Small ruminants are owned in most households (3.4 sheep and goats per household).

The main arable crops are cassava, yams, and maize. Subsidiary crops include cocoyams, pepper, cowpeas, banana, tomato, pigeon peas, and okra. Palm trees are harvested and the fruit is processed to provide oil. In the forest area, cocoa, kola, and citrus are grown. In the savanna, locust bean (*Parkia clappertoniana*) and shea butter (*Butyrospermum paradoxum*) trees are allowed to grow and are harvested for their products.

The ILCA alley farming research and extension project was introduced to Owu Ile and Iwo Ate at the end of 1983 (see Atta-Krah and Francis, this volume). These communities had been selected on the basis of their involvement in agriculture in general and small ruminant production in particular.

The land is managed using a bush-fallow rotation system. After clearing and burning, cultivation typically occurs for about 5 years. After this period, the land is allowed to lie fallow for around 5 years. The actual length of the fallow depends on the availability of land and the means to cultivate it. Hand labour is the rule, although some farmers hire tractors to plough their savanna farms. Labour is provided by household members, seasonal migrants from the north, and a few permanently resident labourers from the southeastern states. Labour is generally hired on a task basis.

The potential benefits of alley farming were explained to farmers at community meetings and those expressing interest were offered tree seeds and advice on planting. Critical decisions about the management and use of the trees were left to farmers themselves. Participation, management, and utilization were monitored closely, while a resident government extension agent continued to offer advice to farmers. Seventy-six farmers in Owu Ile and Iwo Ate planted alley farms in the 1st year of the project; 40 more planted in the 2nd year.

The alley farms were planted on land obtained through inheritance (generally from the father, but in one case from the mother), purchase, gift, lease, or loan. Those who originally rented land (whether or not they had continued to make payments) or who were farming on borrowed land, had to receive the permission of the landowners before planting the trees. Although some landowners say that they would be reluctant to allow their tenants to establish alley farms, no cases have come to light of prospective alley farmers being refused permission to plant trees.

Women farming on their husbands' land usually sought their spouse's permission before planting alley farms. Widows, in most cases, established the farms on the land of their late husbands. In 1984, the 1st year of the project, women were underrepresented among alley farmers. Although they account for 60% of the adult population of the two villages, they accounted for only 17% of alley farmers in 1984. However, many women do not regard farming as their primary occupation. Most are engaged in food processing (primarily of cassava and palm oil) or petty trading, in addition to their domestic responsibilities.

In the 2nd year of the project (1985), particular emphasis was given to encouraging women's participation. In 1985, 50% of the alley farms established were planted by women. Therefore, the participation of women in alley farming at the southwestern project site seems to have been determined less by land tenure factors than by the existence of competing demands on their time and the initial approach taken to the extension of the technology.

At Owu Ile and Iwo Ate, access to land for planting trees does not seem to be a constraint on the adoption of alley farming. In this, Owu Ile and Iwo Ate are probably typical of the less densely populated parts of the region (the population densities of Ejigbo and Ogbomosho Local Government areas are 198 and 186 persons/km^2, respectively (Idachaba et al. 1981). Farther south, however, especially in the cocoa-growing areas around Ibadan, Ife, and Ilesha, rural population densities are considerably higher and land is much less readily available.

Writing about the cocoa belt in the early 1950s, Galletti et al. (1956) were already noting that *free* land was no longer available where population density approached 60 persons/km^2 and that most families did not have enough land to allow adequate fallow periods. Data collected by Galletti et al. (1956) also indicated that land held on temporary or permanent grant from other families accounted for about 18% of land in use. This proportion has increased greatly in the intervening years. Between 1952 and 1968, evidence from Ife division indicated that the proportion of land held on permanent lease increased from 15 to 39% (Van den Driesen 1971). By 1968, more farmers in Ife division were lessees than owners of land and only 10% of households had land in reserve. Accompanying these changes was an increase in the proportion of land held on temporary leases. Thus, in areas where land pressure is more intense and the terms of tenancy are more definite and permanent, tenants, many of whom grow food crops under temporary leases, may be disallowed from planting alley farms.

Southeast Nigeria

General features

The land-tenure systems of southeast Nigeria are less well documented, more complex, and more varied than those of the southwest (Francis 1986). Their complexity is largely due to the existence of various categories of land to which different tenure rules and patterns of use apply. The variation between areas is a reflection of differing ecological conditions, population densities, and farming systems. There is also considerable variation in dialect and terminology in the region.

The major sociopolitical divisions of traditional Igbo society are the town (generally known ethnographically as the village group), the village, the localized partrilineage, and the extended family. All of these units, as well as individuals, may own and control land.

The classification of land in terms of the social unit exercising control and ownership is related to two other bases of classification: by spatial arrangement and in terms of use. The spatial categorization of land distinguishes compound land, near farmland, and distant farmland. The classification of land according to use distinguishes groves, pastureland, and farmland. Within the category of farmland, several types of land are distinguished according to vegetation and soil type (Jones 1949; Obi 1963).

Obi (1963) classifies economic trees and plants as a separate category of property distinct from land and movables. Customary law relating to trees treats different types of trees in different ways. The most basic distinction is that between self-sown trees and trees planted by people. If trees are deliberately planted, they belong to the person who planted them. Rights over self-sown trees, in contrast, are generally vested in the owners of the land. Thus, self-sown trees on individual holdings are the exclusive property of the landholder; economic trees growing wild on communal land, however, belong to the entire land-holding group. In the case of communally owned farmland under cultivation, the individual farming the area on which the tree is growing has exclusive rights over the tree during the period of cultivation.

Okwe

Okwe, in Imo State, lies within the forest zone some 10 km southeast of Umuahia. Most of the land is situated on a gently undulating plateau; to the east, the terrain is hillier and the slope is steeper. Soils are sandy and well drained. Mean annual rainfall is a little under 2200 mm. The population density of the Ikuano-Umuahia Local Government Area is 369 persons/km^2 (Idachaba et al. 1981).The 1963 census showed the population density of the Okwe area to lie between 100 and 200 persons/km^2. On the basis of farm sizes, Lagemann (1977) estimated the population density of the Okwe area at 250 persons/km^2 in 1975. Okwe's 276 households, representing an adult population of around 600, are grouped into five subvillages.

At Okwe, there are three main categories of land. Each category has a corresponding land use. Around the compound, there is a multistory cropping system with a diversity of trees (kola, pawpaw, coconut, citrus, and others), and arable crops (*Telfaria*, pepper, cassava). The compound area is cultivated continuously and household waste and animal manure are returned to it. "Near farms" are the second category of land. This land is generally cultivated in alternate years, although the pattern of rotation varies according to land availability and fertility. Cassava, *Telfaria*, and other vegetables and condiments are grown on this land. The third category of land is "distant land." The main crop on distant land is cassava (maize, melon, and bitter yam are also grown). This land has a 6-year cropping cycle and reverts to fallow after the harvest of a single crop of cassava.

As the availability of sites near the road is limited, compound land is often purchased in Okwe. Patterns of ownership of both near and distant farmland are largely determined by inheritance, which is the principal, but not the only, means through which land is obtained. Like other property, land is inherited patrilinearly. Following the principles of Igbo inheritance, the eldest son of the deceased acts as the administrator of the estate. The different types of land are shared separately. They are divided first into the number of shares according to the number of wives with surviving male offspring. Full brothers may then divide the land between them or, more commonly, continue to hold the land jointly, sharing it either before or after clearing. After inheritance, the most common source of land is the redemption of a pledge originally made by a deceased ancestor. Such land is the individual property of the redeemer.

Land ownership in Okwe is predominantly individual; however, there are collective mechanisms for management. In this discussion, the most important of these is the setting of rotations on distant land by the subvillage. The territory is divided into various zones and exploited according to a 6-year cycle, which determines which land will be cultivated in any particular year. Following the harvesting of cassava in the subsequent year, the land reverts to fallow for another 4 years. The system is well established and generally believed to be of long standing. It seems that the subvillage rarely exercises any sanction to maintain the cycle of rotation; indeed, it is unclear whether it could do so. However, pests (mainly bushpigs, grasscutters, and rodents) cause severe damage on the edges of farmed areas and would constitute a real hazard to anyone farming in an otherwise uncultivated area. Those without land in one of the zones being cropped in any particular year rent from those who have excess land or from absentee owners. These leases are annual arrangements. The lessee clears the land and is entitled to use or sell the wood obtained. Women obtain land from their husbands or may rent for themselves.

Timber trees remain the property of the landholder's kin group. Rather than being shared on inheritance they are held jointly and income from them is divided among the heirs. Any member of the community may hunt or fish in Okwe territory.

The tenure of palm trees is also differentiated by land-use zone. Palm trees on compound land and near farms, which are often deliberately planted and include improved varieties, are held individually. In contrast, the palm trees on distant land, which are generally self-sown, are communally controlled.

What are the implications of the land and tree tenure systems outlined here for the acceptability of alley farming? The individual tenure of compound and near farm land is secure and includes the right to plant trees. However, the relatively small area of compound land is the site of an intensive and complex agricultural system, and the opportunity cost of land here is relatively high. Near fields, however, would seem to be suitable for alley farming.

On the outlying fields, which constitute the most important category of land in terms of area and production, and where the question of soil fertility is more critical, the system of land use and administration makes the adoption of alley farming problematic. The cropping cycle includes only one period of cultivation; after the harvest of its intercrops at the end of the 1st growing season, cassava is left until its harvest with minimal weeding or other management. In southwest Nigeria, where land is cropped for 2 seasons a year for several years before being allowed to revert to fallow, the adoption of alley farming does not necessitate extra weeding in the 2nd and subsequent years of cropping as the land remains under cultivation. Under the land-use system at Okwe, however, land would normally be abandoned once the cassava crop was harvested; thus, any labour expended on maintaining the alley farm is an additional input. Given the relatively poor, acid soils of the area, the potential of the trees to produce enough mulch during the year following planting to enable the extension of the cultivation period beyond this year is poor. Furthermore, if the cropping period was extended by an individual farmer, the new system would be out of phase with the collectively recognized system of rotation practiced at Okwe. That farmer would soon be farming in isolation and risking crop damage from animals. Finally, those obliged to rent land would have no incentive to invest in soil fertility as lease arrangements are always for a single cropping cycle.

On-farm trials of alley farming were introduced at the two sites in the southeast in a similar manner to that described for the southwest. The pattern of decisions made by participants reflects the institutional constraints described (Fig. 2). In 1984, 8 Okwe farmers planted the trees; in 1985, 11 more planted. In the 1st year, *19 browse tree planters (4 women)*

Compound land	*Near farmland*	*Distant land*
1	15 (4 widows)	3

Farmer's own: 11
Late husband's: 4

Fig. 2 Plantings by land type and gender, Okwe.

only one woman, a widow, planted trees. Three of the 11 planters in 1985 were women and all 3 were widows. The question of women's participation in browse tree planting in the southeast and its relation to land use rights is considered in the next section.

All but four of the farmers chose to plant on individually held near farms. In one case, this was on abandoned compound land. The four women planted on the individually owned near farms of their late husbands. One farmer planted next to his compound. In three cases, trees were planted on distant land; all of these were unsuccessful. Two feed gardens established on distant land in 1984 were abandoned as the land returned to fallow. The alley farm planted on distant land in 1985 never established properly because of waterlogging of the soil.

Mgbakwu

Mgbakwu, the second community in the southeast where ILCA has been conducting on-farm trials, is 8 km north of Awka in Anambra State. It lies in gently undulating, open terrain in the transitional savanna zone. Soils are Ultisols and are low in nutrients and pH. Mean annual rainfall is around 1 800 mm with a bimodal distribution. The population density of Awka Local Government Area is 432 persons/km^2.

Mgbakwu consists of 983 households, equivalent to an adult population of around 2 800. The population is segmented into *umunna* ("sons of the same father"), each consisting of around 10 households. *Umunna* are exogamous groups and are the important social unit for the control of land. The mean number of adults per household is 2.8.

As in Okwe, three major types of land may be distinguished: compound or house land, near farmland, and distant farmland. All adult male members of an *umunna* are entitled to a plot of land on which to build a house. The house plot and the house on it would be inherited by his children. The *umunna* does, however, retain some reversionary rights: if a plot of house land is not developed by an individual within a reasonable period, the *umunna* may, after giving due notice, allocate it to another applicant.

Trees are planted around the compound and the main arable crops are cocoyam and bitter leaf. Cultivation in the compound area, which benefits from the application of household waste and animal manure, is continuous. As at Okwe, goats and sheep are kept confined in the compound and feed is carried to them.

Near farmland is situated close to the residential area and is cultivated either every year or in alternate years. The main crops are cocoyam, cassava, yam, and vegetables. Household sweepings are often carried to this area. Trees, such as pawpaw, plantain, and African breadfruit, are also fairly common.

Distant land owned by Mgbakwu residents extends about 10 km to the north of Mgbakwu. The main crop on this land is cassava. It is planted on its own in ridges or, less frequently, intercropped with yam in mounds. Pigeon pea is also grown on distant land. After the harvest of cassava, the land is left fallow for several years. The land-use cycle on distant land is usually 4 or 5 years long.

With the exception of land already allocated as house plots, almost all near and distant farmland is owned by *umunna*. Typically, such a land-holding unit consists of 10 to 60 adult males jointly owning an area of near farmland and blocks of distant land. Allocation of both types of land takes place annually following the major town festival of *Egwu Alusi* at the beginning of the rainy season. The near farmland is divided and members choose their shares in order of seniority within the lineage. Near farmland is reallocated every 1 or 2 years, and the *umunna* may place restrictions on the crops that may be grown there.

The *umunna* also decides which blocks of distant land will be exploited in any season. The adult members, accompanied by prospective tenants, go to the land in question and divide it into plots, whose boundaries are marked with sticks. The area of each plot is around 700 m^2. All adult male members of the *umunna*, whether or not they are a resident of Mgbakwu, are entitled to a plot in each block of land exploited. The lineage members select from the plots in order of seniority. Women usually either obtain land through their husbands or, where this is not sufficient, rent it. Widows are entitled to shares of both near and distant farmland from their late husbands' *umunna*.

Surplus land is rented. Sometimes the proceeds are shared immediately; in other cases, the money may be kept for collective purposes such as funerals and other ceremonial expenses. Individuals allocated land may opt to rent any excess land. The money from such transactions is their own. Renters are mostly individuals from other Mgbakwu *umunna* that do not have sufficient land available for that season. Leases of distant land are always for one farming cycle only. Near farm plots are also rented; however, this is less common than the renting of distant land. The period of rental is one cropping cycle.

Sales and pledges of land are both recognized in Mgbaku; however, they occur only rarely. The collective ownership and control of land means that only the *umunna* can authorize such transactions.

Trees may be planted on collectively owned, near farms by members of the *umunna*. They remain the property of the planter, who has exclusive harvesting rights. Both men and women may plant trees. The land, however, remains vested in the *umunna* and there is no guarantee that the planter will have use of the land in future cycles (although they may be permitted to choose the same plots when land is reallocated).

Trees are not planted on distant farms. Timber and other useful trees (e.g., raffia) in wooded areas belong to the *umunna* owning the land on which they grow. Proceeds of sales go to the group. Firewood may be collected from any area of distant farms except cultivated areas. In contrast to Okwe, firewood is not sold outside the community. Any member of the community may hunt or fish in Mgbakwu territory.

The systems of land and tree tenure found at Mgbakwu differ from those found at Okwe. The predominant unit of ownership at Mgbakwu is the *umunna*; even individually held land is obtained from this group. As at Okwe, however, rights over compound land are both individual and secure, and tree planting in this area is a universal practice. The communal ownership and control of both near and distant farmland, however, has important implications for the feasibility and acceptability of alley farming. Although *umunna* members have the right to plant trees on near farmland, the right to cultivate this land continuously is not guaranteed. On distant land, the *umunna* decides which blocks to exploit in any year and, thus, the length of the fallow period. The cultivator's rights to use this land extend for a single cropping cycle and the land reverts to the *umunna* after the harvest. Even when the block is cropped again 4 or 5 years later, the land will be redivided and the individual is likely to receive a different portion. Again, those renting land only have its usufruct for a single season. Thus, neither *umunna* members nor tenants have any incentive to invest in soil fertility. Even were an alley farm to be planted on distant land, at Mgbakwu as at Okwe, weeding labour would be additional. Also, extending the cropping period would leave the cultivator farming in isolation, with the associated risks from pests, when the other members of the *umunna* moved to another block of land.

In 1984, 11 Mgbakwu farmers established browse trees; in 1985, 7 more farmers planted (Fig. 3). The participants in 1984 were all men. The low participation of women, both here and at Okwe, suggests that they were disadvantaged in their access to land for tree planting. In 1985, a female senior technician was posted to the southeastern sites. One of her responsibilities was to examine the reasons for this phenomenon. In the same year, five of the seven plantings were by women. As in Okwe, all of these women were widows.

Even though wives were completely absent from the list of participants at both Okwe and Mgbakwu, they often played an important role in the management of the feed gardens and alley farms. In particular, they were usually responsible for the weeding. They also cut the trees for fodder. All the goats in the household (which are owned individually) received the benefit of browse, which is cut by either the husband or the wife. The structure of agricultural decision-making within the Igbo household is more responsible for the apparently low participation of women in the projects than are the land-tenure rules.

Thirteen plantings (72%) were made on individually owned compound land. Seven of these were on the farmer's own compound. In another three cases, trees were planted on plots of house land that had been allocated to the farmer but on which building had not yet taken place. The other three farmers planting trees on individually held land were women. One planted within her son's compound, where she lives; another planted on a plot of house land where her son is to build a house; the last planted the trees on a plot of house land allocated to her late husband.

18 browse tree planters (5 women)

Compound land	*Near farmland*	*Distant land*
13 (3 widows)	5 (2 widows)	0
Own compound: 10 Son's compound: 2 widows Late husband's compound: 1 widow	Collectively owned: 3 (1 widow) Individually owned: 1 (1 widow) Rented: 1	

Fig. 3. Plantings by land type and gender, Mgbakwu.

The other five plants were made on near farmland. One woman planted on land that her husband had owned personally. In three more cases (two men and one woman), trees were planted on the collectively owned land of the planter's *umunna* (or, in the woman's case, her late husband's *umunna*). The other planting on near farmland was the only case at either site in which trees were planted on rented land: a man planted trees on a piece of near land rented from his wife's family. The land was *umunna* property held by the in-laws on a temporary grant. It was abandoned after the crops were harvested. In no case were trees established on distant farms.

Conclusions

Land-tenure systems are critical in determining the acceptability and viability of alley farming. This does not mean that they operate as inflexible constraints on agricultural innovation. As the example of southwestern Nigeria shows, land-tenure systems are subject to change and evolution under the influence of land pressure and changes in agricultural techniques. Furthermore, any land-tenure system may include many different categories of land to which different tenure rules and patterns of use apply. Patterns of technology adoption will be shaped by the opportunities and constraints presented by the rules of tenure. Thus, a knowledge of the system, its dynamics, and the potential "niches" for innovation that exist within it is required in both the design and the extension of alley farming and related agroforestry technologies.

Just as the potential acceptability of alley farming depends on the category of land being considered, so the ability to plant and use trees will differ according to the social status of the cultivator and the way in which access to the land was obtained. Key distinctions to be taken into account here are the implications of the system for men as compared with women, for natives as compared with strangers, and for landowners as compared with tenants.

As alley farming permits the extension of cropping periods, its benefits are greatest in situations where land is scarce. Considering the dynamic nature of land-tenure systems and their role in determining the success of ally farming, it is important to know what effects increasing population pressure and agricultural intensification will have on these systems. In the southwest, rising population densities, agricultural commercialization, and the spread of cocoa cultivation have led to the individualization of rights and the emergence of tenancy. For landowners, individual and long-term control over land have created conditions that are conducive to alley farming. The growing importance of tenancy in the region (in particular, temporary leases), however, means that a large and increasing section of the agricultural population may be excluded from its benefits.

Under the higher population densities of the southeast, a spatial differentiation of land has emerged. Here, intensively cultivated compound farms are associated with the confinement of livestock and the recycling of household and animal waste. Lagemann (1977) compared agricultural systems in three ecologically similar parts of the southeast with differing population densities; the least densely populated area studied was Okwe. His findings indicate that, with greater pressure on the land, the size of the compound farm and the complexity of recycling and intercropping within it increase. More livestock is also kept. At the same time, the total area of land cultivated per household declines; the plots cultivated outside the compound are smaller and more fragmented. Fallow periods on these plots are shorter, the soils poorer, and yields lower in the more densely populated areas.

The compound farm appears always to be held under individual tenure (or, more accurately, under the control of the household head). Its increasing importance under conditions of agricultural intensification seems to admit the incorporation of alley farming into the system (although the area is typically already densely planted with both tree and annual crops). It is unclear from the available evidence how increasing population pressure affects the tenure of other categories of land. Low, declining soil fertilities in the more densely populated areas make the need for innovation more urgent. However, the case studies considered here suggest that the pressure on land neither leads to a breakdown of communal systems of land ownership and management nor to the emergence of individual proprietorship. ILCA is now examining the possibility of a community-level initiative to modify cropping cycles and rotations on communally controlled land. In the absence of such a development, it is difficult to imagine any way in which the systems of communal control outlined in this paper could evolve into individual proprietorship.

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Economic returns of alley farming

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Abstract — To date, economic evaluations of alley farming have focused on how profitable it is for the individual farmer. However, the work of physical scientists indicates that the individual farmer can capture only some of the benefits; others accrue to society as a whole. The decision to invest in alley farming is an individual one. However, as farmers are aggregated to groups and groups to regions, the benefits and costs to these aggregates increase. This paper suggests mathematical programing as a method for the ex ante evaluation of alley farming at different levels of aggregation. Such models measure the benefits to society and information can be incorporated as it becomes available. Alley farming is compared with other technologies that maintain fertility and control erosion in the long term.

Introduction

Land degradation is one of the most pressing problems in tropical Africa. Alley farming, which has been tested over a wide range of environments, is one technology with the potential to overcome this problem.

The list of benefits from alley farming includes continuous cropping and fertility maintenance. This implies savings in land clearing, fertilizer costs, and potentially higher income through yield increases. The demand for new land may also slacken. As a result, valuable forest land will be saved. Alley farming also reduces erosion, thereby reducing on-site and off-site costs incurred by erosion damage. The trees used in alley farming can contribute to animal feed and stems can be used for yam staking and firewood production; meat production can also be increased.

This brief list shows that alley farming benefits individuals as well as society. There has been little discussion in the literature on alley farming of the benefits to society not captured by the farmer (positive externalities). This paper focuses on the benefits of alley farming to society. The development of a methodology to evaluate these benefits is emphasized. This will help to identify major gaps in the available data, thus pointing out areas for future research.

Review of previous work

A sizable body of literature on alley farming in tropical Africa has developed over the past few years. Major contributors include the International Institute of Tropical Agriculture (IITA), the International Council for Research in Agroforestry (ICRAF), and the International Livestock Centre for Africa (ILCA). This work has been reviewed by Sumberg et al. (1985).

The agronomic work indicates that alley farming allows continuous cropping with moderate, stable yields and is an alternative to the traditional bush-fallow system. The economic work has investigated the profitability of alley farming for different agricultural systems as viewed by individual farmers. Raintree and Turay (1980) focus on alley farming and rice production; Verinumbe et al. (1984), minimum tillage; Hoekstra (1982), alley farming under semi-arid conditions; Ngambeki (1985), alley farming in relation to the use of herbicides and nitrogen. All these studies conclude that the returns from alley farming, combined with various crop-production systems, are high enough to provide an incentive for farmers to adopt the technology.

Sumberg et al. (1985) investigates the economics of feeding prunings, which are in excess of soil fertility maintenance requirements, to small ruminants. They conclude that crop or livestock production from the excess foliage is about equally profitable. Francis (this volume) focuses on land tenure as a potential institutional constraint to adoption. He concludes that land tenure problems are important but that generalizations cannot be made because of the relative flexibility of customary law.

The economic literature suffers from several weaknesses. Most studies use experimental station data, data that may be unrealistic under farm conditions. Focusing only on the individual farmer, the studies ignore major benefits of alley farming on society, with several consequences. The real benefits of this technology are underestimated. Thus, alley farming does not receive the attention it deserves by researchers and policymakers. This may lead to a misallocation of resources. Also, economists do not provide physical scientists with feedback. Thus, research into profitable areas may remain unexplored.

This paper identifies inputs and outputs and formulates them into a general model for the evaluation of alley farming. This model is then modified to suit the purposes of each step of analysis.

Objectives

The objective of this paper is to develop a methodology suitable for measuring the benefits of alley farming to society. Management decisions at the farm level are generally analyzed in the context of maximizing expected net income over a certain time. Rational individuals calculate the amount of income they expect to receive over time and compare this to the expected income using the old technology (Lee 1980). Individuals may reach different investment decisions, depending on discount rate and the length of their planning horizon.

A farmer's decision on whether to adopt alley farming depends on the institutional environment in which that farmer operates. Whenever there is a divergence between individual (private) and total (social) benefits and costs, an externality is present (Dahlman 1979). When deciding whether to adopt alley farming, the farmer considers the additional quantity of, say, maize produced, the price of maize, and the change in production costs. The farmer will also estimate the number of years that more maize can be harvested and what the total additional crop is worth today. If this value is sufficiently higher than the value of the maize crop without alley farming, the farmer may decide to adopt alley farming.

Several key points may lead to this decision. The better the information on the potential of alley farming, the more accurate will be the farmer's assessment. Farmers only consider that portion of their income that they keep; they count only those costs that have to be paid. Thus, a farmer does not consider the off-site savings from alley farming. The farmer does not place any value on reduced erosion, which will lower the costs of maintaining irrigation canals, for example (Southgate et al. 1984). Also, if the farmer's right to use the land is limited to only a few years, the incentive to plant alleys will be reduced because the whole benefit of the investment will not be reaped (see Francis, this volume).

It is usually argued that more secure property rights are an incentive to investment in resource conservation. Southgate et al. (1984) point out that the institutions have to be such that the activity of asserting private-property rights does not generate environmental damage as a by-product.

Looking at the benefits and costs of adopting alley farming within a region, it is apparent that what does not benefit the farmer may benefit the inhabitants of the region. Similarly, costs not paid by the individual may be paid by people within the region. Suppose that a whole village has adopted alley farming and that surplus maize is marketed in a nearby town. The increase in maize output will raise farmers' income and consumers in the town will benefit from lower prices. Similarly, the development costs of the new technology are likely to be paid from outside sources. If the extension service is supported from local funds, however, each farmer would pay a share.

This example shows that costs and benefits can be internal or external depending on the level of aggregation, i.e., whether an individual, a village, a region, or a country is considered a unit. As the level of aggregation increases, more of the costs and benefits become internal. At each level, inputs and outputs must be listed and it must be decided which costs and benefits are internal and which are external.

For the purposes of evaluation, all benefits from a new technology are assumed to accrue to society rather than to individuals. There are at least two reasons for this view. First, the decision to adopt is made by individuals who only consider their private costs and benefits. The aggregate benefits of adoption go to all farmers; as individuals, however, farmers are only concerned about their own share. Second, the sum of the benefits expected by each farmer is usually not equal to the benefits that are actually received. Each farmer may expect returns to increase when more fertilizer is applied. However, a decline in prices because of the increase in total output may result in lower returns. For policy analysis, it is useful to assume that decisions are made by individuals and that benefits go to society.

From this example, it is clear that society gains from a portion of the benefits, be they additional returns or reduced costs; which portion of the benefits the farmer can retain depends on the institutional environment in which that farmer operates. The institutional, economic, and political environment also determine the farmer's planning horizon.

Evaluating alley farming

A general technique for evaluating the economic benefits of a new technology is presented here. The procedure is developed in steps corresponding to the level of aggregation (i.e., farmer, regional, or national level). This level reflects the adoption process of the technology. The effects of adoption on the economy also change with the level of aggregation, thus requiring adjustments to the model. Similarly, the benefits and costs, whether internal or external, are identified at each level in the suggested evaluation procedure.

Evaluating the benefits

Two procedures are typically used to evaluate the benefits of agricultural research: the economic surplus (or index number) approach and the production function approach (Martinez and Sain 1983). Both procedures are retrospective evaluations.

The economic surplus approach is more appropriate for two reasons. First, it is less data demanding and, second, there are methods that allow for previous evaluation of investment into research. This approach is based on the concept of producers' and consumers' surplus.

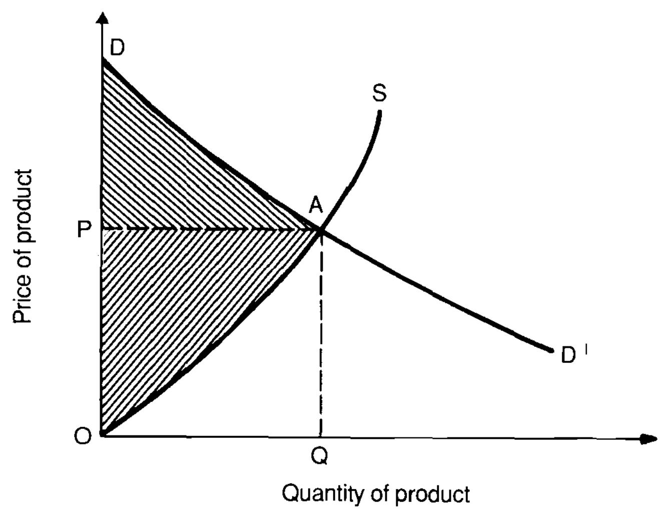

Fig. 1. Supply and demand curves and the measurement of consumers' and producers' surplus.

Benefits to consumers (in the form of surpluses) are measured by the area under a demand function (*DD'*) down to the equilibrium price line (*PA*). Benefits to producers (producers' surplus) as measured by the area above the supply function (*OS*) up to the equilibrium price line (Fig. 1). The sum of both surpluses represents the benefit to society. Externalities on the demand side are not accounted for here; thus, this is only a partial analysis.

The introduction of a new technology may increase productivity; this would shift the supply function to the right. The change in area represents the increase in benefits to society (Fig. 2). The change in consumers' surplus is given by the areas P_oACP_n plus *ABC*. The gain is due to a decline in price from P_o to P_n and an increase in quantity from Q_o to Q_n. The change in producers' surplus is given by the area *OCB* minus P_oACP_n. Both the supply and the demand functions can be estimated econometrically. The supply function contains a research variable, which measures the function shift attributable to research expenditures. The change in consumers' and producers' surplus is then calculated. It has been shown that, regardless of the mathematical form of the function, the key value to be estimated in this model is the percentage change in the value of production attributable to research.

Model requirements

The described procedure has been used mainly for retrospective (ex post) evaluation of technology. To help the agricultural policymaker in making decisions, however, an estimate of the potential (ex ante) benefits to alley farming is required. An ex ante evaluation model must be able to represent at least some of the aspects of the physical, biological, and human environment in which the farmer operates. It should be possible to capture some major reasons for farmers' decisions. The model should be flexible in that it should be able to evaluate a large number of production-technology alternatives and be applied at each level of aggregation. However, the

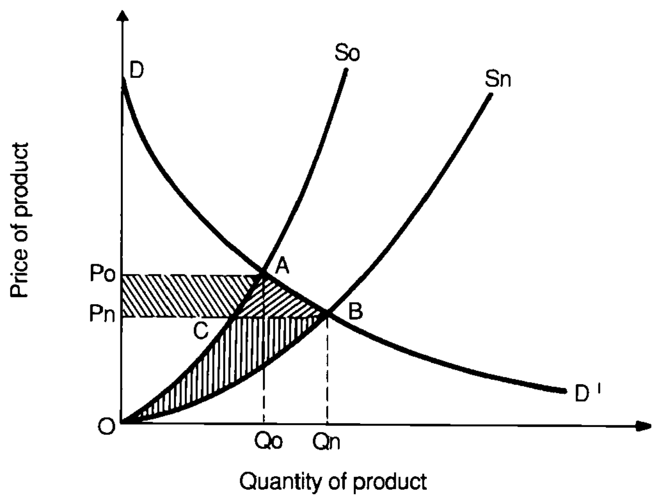

Fig. 2. A theoretical model for measuring the social benefits of agricultural research (source: Zentner and Peterson 1984).

model should accommodate changes in assumptions. It should be inexpensive to run, the output should be easy to interpret, and the data requirements should be manageable.

Mathematical programing, a technique that has been widely used, fulfills these requirements (for a review of recent developments in mathematical programing, see Anderson et al. 1977; Norton and Solis 1983; Vogel 1984). The benefits from alley farming could be evaluated in three steps representing three levels of aggregation (Table 1).

This paper discusses only the basic rationale of some model specifications. These are the basic linear programing (LP) model at the farm level, the farm model including risk, and the regional model with internalized demand functions and risk. All models are extensions of the farm-level LP specification. The reformulations are an attempt to include more of the farmers' goals and to capture changes in price behaviour at higher aggregation levels.

Basic model for the individual farmer

The basic LP model can be written as follows:

$$\text{Max } \Pi = p'y - c'x - F$$

$$\text{subject to } Dx \leq b;\ x \geq 0$$

where II is the profit, p is an $n.1$ vector of market-clearing prices, y is an $n.1$ vector of yields, c is an $n.1$ vector of unit costs of inputs, x is an $n.1$ vector of enterprise levels, F is fixed costs, D is a $k.n$ matrix of input coefficients, and b is a $k.1$ vector of resource sand restrictions.

This model assumes that prices, quantities, and coefficients are nonstochastic; i.e., the model does not consider risk. The farmer maximizes profits and is risk neutral. Other goals such as self-sufficiency in food requirements could be incorporated and would appear as restrictions in the technology matrix. Many alternative technologies could be specified and evaluated, and many resources could be incorporated. Labour, capital, and demands for food and its availability could be specified by time period; land could be specified by soil type and slope.

Table 1. Models with levels of analysis and their programing features.

Level	Model features[a]
Farm	LP LP + risk
Region	LP LP + risk Internalized demand functions + risk
Nation	Several regions as LP Several regions as LP + risk Several regions with internalized demand functions + risk

[a]LP, linear programing.

Rotation requirements could also be included. The farmer could consider output prices as given; i.e., they do not change as the quantity that is marketed increases or decreases (the demand curve is horizontal). This implies that this model can only measure producers' surplus, which, in this specification, is identical to private profit. In the early stages of adoption, when alley-cropping farmers are few and scattered, this is a realistic assumption. Only one time period is considered in an LP model. Discounting must be done separately or a multiperiod model has to be developed.

Included benefits and costs

An increase in the gross income of producers has two sources: an increase in crop and livestock production and from the value of the trees to the farmer. Crop output can increase for two reasons, area expansion or increased land productivity. In several regions, crop output is regulated by farm size, which is limited by the scarcity of labour during land-clearing and weeding. Alley farming first reduces and finally frees the labour tied up in land clearing. It increases labour demand for pruning but reduces it for weeding (Table 2). Both tasks fall into the same period. Ngambeki and Wilson's study (1984) on pruning labour is inconclusive on the net effect. This topic needs more on-farm investigation. Perhaps the technology can be modified such that a decline in labour requirements is guaranteed.

Kang and co-workers have demonstrated that productivity may be improved through higher fertility levels, increased water-holding capacity, and reduced erosion (Kang et al. 1981; Kang et al. 1984; Kang et al. 1985). For comparison, data relating crop yield to erosion (Lal 1983) could be employed to estimate yields without alley farming.

Table 2. Benefits and costs measured by a farm-level linear programing model.

Included in model	Excluded from model
Benefits	
Improved fertility (higher average output)	Foreign currency savings for fertilizer and its distribution[a]
Shift to nitrogen-responsive crops(?)	Area expansion in the region because of reduced risk(?)
Area expansion because of net effect of land clearing, weeding, pruning, and labour(?)	Reduced rate of off-site erosion and land degradation
On-site erosion control, if reflected in lower costs to the farmer and higher prices for the crop	Value of conserved land
Stakes and firewood from trees	
Costs	
Loss of land to trees	Contribution to technology development by international and national research institutions
	Extension service

[a] These savings could be calculated using a subroutine.

The benefit to the farmer from fertilizer depends on the responsiveness of the crop to this input. It can be expected, for example, that alley cropping farmers will increase maize production by demanding maize varieties most responsive to nitrogen.

Alley farming may reduce risk in two ways. Under drought conditions, maize planted in alleys suffers less from moisture stress than other maize (J. Mareck, personal communication). This may reduce yield variability and extend the growing season in both cropping seasons. Farmers view this as a reduction in cost and may respond by increasing plant population or area.

Another risk for most farmers is the unreliability of fertilizer supply. This may cause risk-averse farmers to avoid fertilizer-responsive varieties. With alley farming, fertilizer comes directly from the trees; because of the assured supply of fertilizer, the farmer may then choose to plant fertilizer-responsive varieties. If the risk factor of unreliable fertilizer supply is ignored, the model may overestimate production and the farmers' use of fertilizers and chemicals.

Potential benefits from increased production of livestock, yam stakes, and firewood (from the trees) in an alley farm can be measured by including sales in the objective function. In general, the value of a resource increases with scarcity. The value of land and the output derived from it are higher in densely populated than in sparsely populated areas. The price of labour in these areas will be lower relative to the price of crops, stakes, and firewood. Landowners will thus retain more of the profits from their crops and have more wood to sell. The market will reward this practice. This will create an incentive to adopt alley farming.

The costs internal to this model are associated with the loss of crop land to trees. Returns per hectare will be lower. However, Sumberg et al. (1985) argue that farmers now plant at low densities and that plant population could be increased without a sacrifice in yield.

Excluded benefits and costs

The model does not account for some benefits to society. Consumers' surplus, if there is any, is not measured and the estimate of change in producers' surplus is likely to be too low because the risk-reducing effects of alley farming are not included.

A benefit to society from fertilizer savings is the decline in foreign currency expenditures for fertilizer imports, petrol, and vehicles. An estimate of these savings can be obtained by calculating how much fertilizer would be needed to produce the additional output. There will be savings in the costs of labour, but these will be in domestic currency. Other savings may include a reduced rate of off-site erosion (e.g., lower costs of maintaining irrigation canals). Deforestation is slowed; this, in turn, may slow desertification. The list of such benefits can be extended, but they will be difficult to quantify. Costs external to this model are those of technology development and extension.

In summary, this model accounts for a considerable portion of the benefits of the new technology. Some additional benefits can be estimated using the information generated by the model. The model overestimates producers' surplus from risky crops and ignores the risk-reduction effects of alley farming on these crops. However, these effects are likely to be small compared with the benefits from fertility gains. In total, it can be assumed that this model underestimates the benefits of alley farming.

Basic model for the risk-averse farmer

Small farmers, especially subsistence farmers, are usually averse to risk. It is typically assumed that risk can be measured by the variance of net returns.

When risk is included in the model, the objective function must be reinterpreted. The farmer is now assumed to maximize utility rather than profit. Aggregated utility can be considered a benefit to society. Prices and yields are assumed to be stochastic and distributed normally. The model for the individual farm becomes as follows:

$$\text{Max } U = p'Mx - c'x - \varnothing \ (x'\Omega x)^{1/2} - F$$

$$\text{subject to } Dx < b; x > 0$$

The changes in rotation are as follows: U is utility, p is an $n.1$ vector of expected prices, M is an $n.n$ matrix of expected yields, $\varnothing$ is the risk-aversion coefficient, often assumed to equal 1, and Ω is an $n.n$ variance–covariance matrix of prices and yields.

The additional feature of this specification is the variance–covariance matrix of prices and yields. The matrix accounts for the effect of prices and the quantities of output, which may move together or in opposite directions. The farmer has some notion about the distribution of prices and yields; however, any particular outcome is a random event.

A farmer averse to risk would consider variance a cost and will attempt to minimize the variance of total net returns of the farm for any given expected net return. For example, if two activities are expected to have the same net returns, the farmer may choose the one with the lower variance. Also, if the farmer knows that the net return of one crop may increase when those of the other decrease, or vice versa, both crops may be planted to minimize risk. This is part of the rationale for intercropping. If alley farming reduces the risk of, say, maize yield, more maize may be grown but not necessarily at the expense of other crops.

The variance–covariance matrix can be obtained from detrended time-series data of enterprise net returns. The deviations from the mean serve as an approximation of the variance (Hazell 1971). The approximation procedure allows the use of inexpensive LP algorithms.

This model requires more information. Only private benefits for a year are measured. The results do, however, represent the behaviour of farmers more accurately. Changes in producers' surplus as a result of changes in risk, which are external in the first model (Table 2), are fully accounted for in this model.

Benefits of alley farming in a region

Most of the benefits from the adoption of alley farming will be internal to the larger region. The specifications of the models can remain unchanged, but two problems must be given attention. The first is aggregation bias. The second arises when the region is large or the number of adopters is great. In that case, information on demand has to be incorporated into the model. A regional model is described here.

When farmers are aggregated to groups or regions, constraints faced by individual farmers may not show up as constraints for the group or the region. For example, if farms with surplus land but a labour constraint and farms having surplus labour but a land constraint are aggregated, neither individual constraint may show up as an aggregate constraint. Therefore, the results of aggregate models tend to overstate the production of the most profitable and least risky crops. This can be avoided, to some extent, by aggregating farms facing the same constraints (Frick and Andrews 1965; Miller 1966).

When larger regions are considered, the assumption that changes in output have no influence on price becomes unrealistic. Information on demand should be incorporated. An estimate of elasticity would be sufficient. The output-price component of the second equation is then replaced by a linearized consumer-surplus function (Hazell and Scandizzo 1974).

This type of model has two advantages. First, they limit aggregation bias. Because output price is functionally related to quantity, an increased output of one crop leads to a decline in its price and makes the other crops more profitable. Resources are reallocated to the production of these other crops. Second, both producers' and consumers' surpluses can be calculated.

Which model specification should be used for a regional or national situation depends on the available information. From a theoretical standpoint, LP models that include risk are appropriate for regions or countries as long as changes in output have a negligible influence on price. If that is not the case, the demand functions should be incorporated.

Table 3. Benefits and costs measured by a regional or national programing model (internalized demand functions + risk).

Included	Excluded
Benefits	
Changes in producers' and consumers' surpluses because of the costs and benefits listed for the basic, individual-farmer model (see Table 2) and because of area expansion as a result of reduced risk	Foreign currency savings for fertilizer and its distribution Reduced rate of off-site erosion and land degradation Value of conserved land
Costs	
Contribution of regionally or nationally financed institutions to technology development and extension	Costs paid by international centres and donors

Which of the benefits and costs from alley farming are internal to the region or country will depend to a great extent on regional size. Whether these costs and benefits can be accounted for in the model again depends on available information. Assuming that aggregation bias can be limited, it seems that even complex models underestimate the benefits of alley farming (Table 3).

Rate of adoption

The suggested models provide a rough estimate of producers' and consumers' surpluses for any given year. These benefits accrue over time, however, and investment or subsidy decisions should be made on the basis of net present value in relation to other investment opportunities. The net present value of alley farming depends largely on its rate of adoption. This, in turn, is influenced by the farmer's assessment of alley farming. Investment in extension can play a critical role in whether alley farming is adopted. Demonstrating the many potential benefits of alley farming to policymakers may help to encourage such investment.

Conclusions

Considering the available information on alley farming, the estimate of its benefits is likely to be conservative. The discovery and assessment of more benefits, to both the farmer and society, will provide policymakers with the incentive to allocate more funds to research and extension. Subsidizing alley farming may be a worthwhile investment if the enterprise benefits society as a whole, even though it may be unprofitable for individual farmers.

When assessing the benefits, an interdisciplinary approach is necessary.

In the coming years, more information will be collected and the assessment of at least some benefits will begin. The results will have to be compared with other techniques capable of maintaining soil fertility in the long run.

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Hedgerow intercropping: some ecological and physiological issues

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Abstract — Productive and useful woody species as in managed agroforestry systems have arisen through evolutionary adaptations in response to environmental stresses. Some relevant aspects of nutrient turnover, climatic exploitation and regrowth capacity of wood species are discussed. The limits to biomass production have been modeled and can be assessed. It is now known that the proportion of assimilates assigned to fine-root turnover can, in some cases, equal litter fall; however, total carbon budgets for hedgerow intercropping have yet to be investigated. Where plant biomass is removed from the site (e.g., as crop yields, leafy fodder, etc.), long-term benefits to the soil will be diminished with no inputs. This trade-off needs thorough investigation. In much of hedgerow intercropping, yield sustenance is probably because of the short-term effects of soil and environment. This is made apparent if the effects of tree cover in space and time are compared and contrasted by modeling the situation.

Some ecological issues

Evolution

Over the centuries, man has selected, arranged, and managed mixtures of plant species in many ways to achieve sustainable yields of food and to provide other products. Some of these land-use systems include woody perennials. Woody perennials, like all other forms of plant life, have evolved by overcoming problems of survival through stress tolerance. They may also have evolved, in some cases, with the attributes of "ruderals" (plants adapted to disturbed sites) (Grime 1977). This has several implications for agroforestry.

It is important to realize that any species will have morphological and physiological attributes that can be associated with a specific set of ecological needs. These attributes will also inevitably establish the potentials and limitations of that species as a productive, useful plant in any managed agroforestry scheme.

To improve species selection and awareness and the range of feasible management techniques, one must understand how a species evolved and its ecological capacity. For example, in a nutrient-poor environment, a relatively fast-growing, "competitive" woody species is more likely to suffer early nutrient stress than a slower-growing, "survival" type. A species with mainly "survival" characteristics cannot be expected to produce biomass at a high rate. Thus, after being lopped in a hedgerow system, such a species will not respond quickly with renewed growth.

Recycling nutrients

Woody perennials have a greater capacity for nutrient recovery from lower soil horizons than annual crops and perennial grasses. However, the capacity for recovery is highly dependent on the root volume (depth) exploited, as well as the level and duration of rooting activity. Indeed, nutrient recycling (and ultimately microsite enrichment under trees or bushes) depends not only on these variables but also on the level of nutrient accumulation in the plant and the longevity of leaves and fine roots (and nodules, for leguminous species). All these factors, by themselves or in combination with others, are attributes that have evolved to ensure a place, or niche, for the species (Pianka 1978).

Exploiting the climate

The ability to exploit favourable climatic periods more fully than seasonal or annual species is a characteristic often claimed for trees, bushes, and woody vines. This is because woody species have a permanent structure supporting a readily emergent or evergreen leaf canopy. In fact, woody species demonstrate a wide range of phenotypic behavioural responses (Huxley and van Eck 1974; Huxley 1983a). This indicates a variety of different tactical approaches to the problems of survival, competition, or success as a ruderal. Moreover, these responses can be modified when a particular species is subjected to a change of climate. This can result in variations in the evergreen or deciduous quality of a species.

An understanding of reactions to climatic changes is important. Such knowledge can help determine whether a species will adapt to change in location or how best to "entrain" a species (by lopping or irrigating at an appropriate time) to a more suitable pattern of growth. Carr (1974) demonstrated that irrigated tea not only produced more during the dry season but also had a different "entrainment" pattern (Fig. 1). Because hedgerows are regularly lopped, their capacity for entrainment and the consequences of their entrainment pattern need to be fully understood.

Regrowth capacity

In many woody species, existing dormant buds can resprout below a cut shoot apex. Both the endogenous and exogenous mechanisms control the number and rate at which such buds will sprout. These mechanisms and the plant's bud morphology (Fig. 2) are affected by the plant's genetic resolution of its ecological requirements. That is, the plant must either exploit its immediate surroundings (where leaves can be organs of aggression) or conserve environmental resources to survive. Research is required on the branching habits and pruning responses of multipurpose trees.

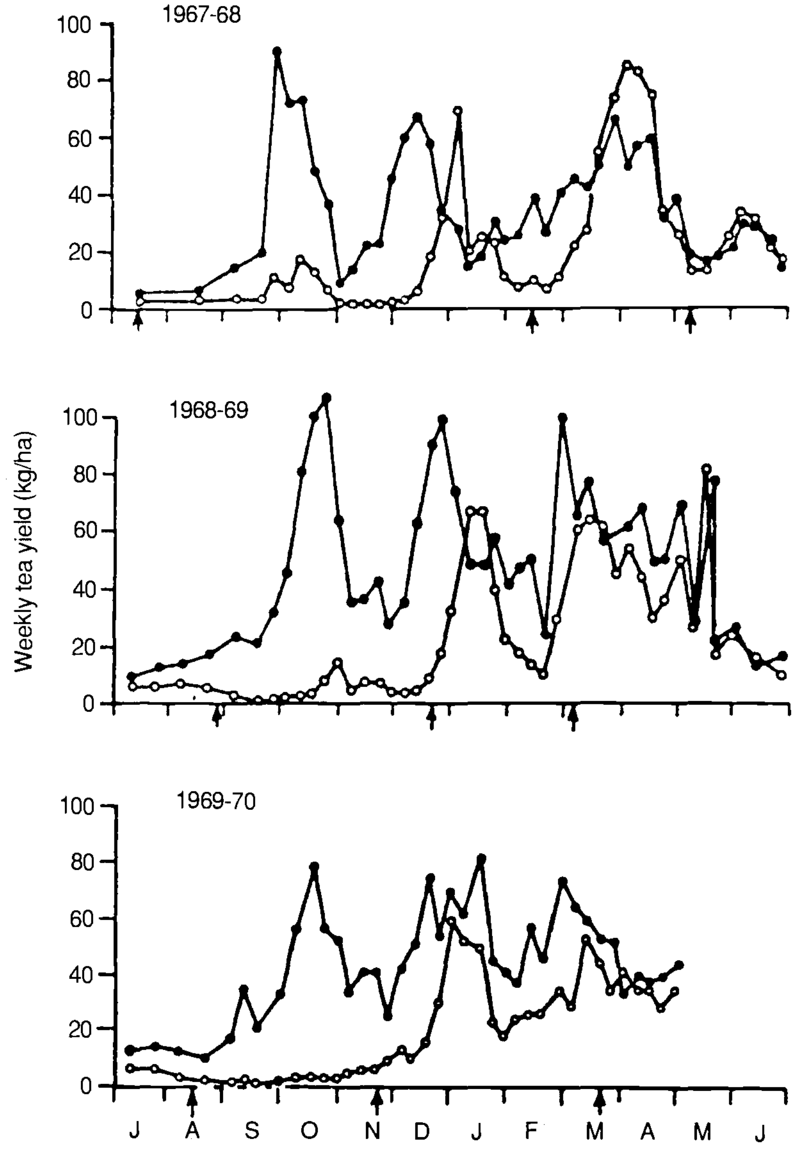

Fig. 1. Tea yields in relation to season for unirrigated bushes (open circles) and irrigated bushes (closed circles) (arrows refer to fertilizer applications) (source: Carr 1974).

Ecological lessons for agroforesters

The rather complex, managed systems of agroforestry can show us the survival strategies adopted by plants growing in various environments. An understanding of these strategies would be useful in deciding which woody species should be used in

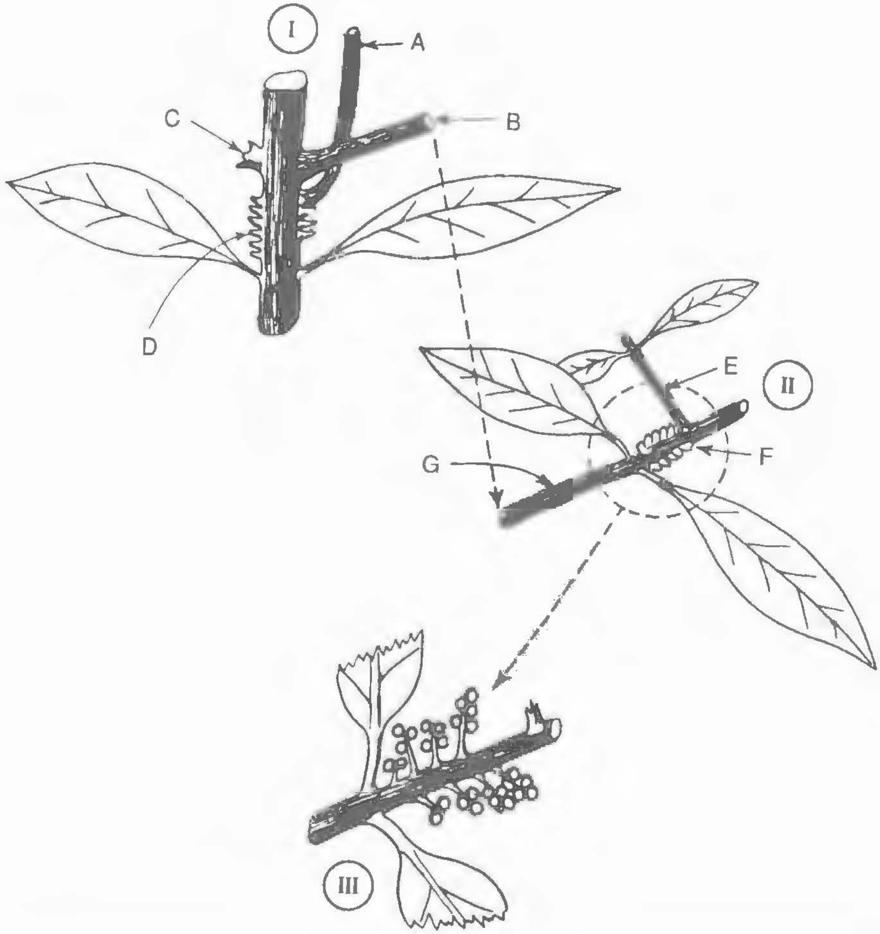

Fig. 2. The bud series that occur in the axils of leaves of *Coffea* spp. I, vertical (orthotropic) shoot; A, sucker (orthotropic); B, primary branch (plagiotropic); C, "head of series" bud; D, bud series (4–6); E, secondary branch (plagiotropic); F, "head of series" bud often missing; G, primary branch; III, series buds develop into inflorescences (3–6 flowers each).

a particular agroforestry site. It would also help in setting up a successful management system.

Limits of biomass production

Genetic improvements in most crops have been more the result of increasing the harvest of dry matter than increasing net carbon accumulation (Gifford and Evans 1981; Cannell 1985). Some yield improvement has been achieved with improved crop ideotypes and species mixtures. The maximum dry-matter production by an actively photosynthesizing plant canopy where water and nutrients are freely available is predictable. The maximum potential for a defined growing season (or seasons) can also be calculated (FAO 1978).

Table 1. Rough ranges of net biomass production (*A*, t/ha per year) for different ecozones and expected ranges of plant dry matter ratios (*B*, % of total).

Biomass production		Dry matter ratio		
Ecozone	**Range**	**Plant part**	**Fruiting**	**Nonfruiting**
Semi-arid	5–15	Roots	11–22	15–30
Seasonally arid	15–25	Stem[a]	18–30	25–40
Highland tropics	25–35	Leaves	15–26	20–35
Lowland humid tropics	35–45	Fruits	≤35	—

Note: For any ecozone, $A \times B$ is an estimate of potential yields for multipurpose trees that may be reduced by incomplete ground cover, poor management, pests and diseases, or bad weather. The following are "good" seasonal yields (t/ha): maize, 1.5–3.0; cassava, 15–20; grain legumes, 0.5–1.0; sugarcane, 40–60 (about 10% is sugar); oranges, 10–20 (fresh weight); cashew, 1.0–1.5; coffee, 1.0–2.0; tropical hardwood plantations, 25–35 m^3/ha per year; tropical pines, 15–45 m^3/ha per year.
Source: Huxley (1985a).
[a] About 80% of the stem could be usable fuel.

Plants exploiting deeper soil levels, such as trees and some grasses may have a longer growing season than shallow-rooting crops. This is due to their greater access to soil water. Trees also provide a complete canopy for a longer time than do plants growing from seeds. Therefore, adding a tree component in plant mixtures, whether in hedgerow intercropping or another system, may improve the use of available environmental resources. This improvement is restricted, however, by the existing broad limits to biomass production imposed by climate (Table 1).

Obviously, plant canopies are not all the same and do not continue indefinitely in the same structural or physiological state. From a theoretical standpoint, for example, an active canopy of a herbaceous species fully covering the ground should produce more dry matter than a forest. Although forests may have a greater gross production capacity (because of a lower albedo), net production will be lower because of the additional respiratory burden imposed by supporting structures (Kira and Kimura 1983). The recorded estimates of biomass production of different kinds of plant communities (grassland, forest, crops) show considerable overlap (Lieth and Whittaker 1975; Lieth 1978; Cannell 1982). Detailed, comparative biomass estimates of woody and nonwoody plant communities in relation to their respective growing seasons from the same homogeneous site have not been compiled.

There is no recorded data for the total biomass production of managed agroforestry associations. Until such data become available, a good starting point for estimates is the generalized theoretical models of herbaceous plant production (Loomis et al. 1979; Connor 1983) and forest productivity (McMurtrie 1985).

Removal of plant parts

Dry matter distribution

A considerable amount of research has shown that plants, whether woody or herbaceous, partition their accumulated dry matter according to an equilibrium between various "sinks." Thus, at any particular stage of growth there is a functional equilibrium between relative root and shoot growth rates. This relationship can be modified by changes in nutrition, available water, and available light. Fruiting greatly affects the dry matter distribution among the vegetative parts; root growth is depleted the most. The presence of fruits decreases overall vegetative growth; it can also increase the plant's total dry matter production (Ledig 1983; Cannell 1985).

When parts are harvested from trees, the subsequent dry matter production will tend to restore the original allometric relationship between roots and shoots. Thus, factors that tend to limit the activity of leafy shoots will result in a greater proportion of assimilates being used by shoots. Likewise, factors that tend to limit the uptake of water or nutrients will result in a greater proportion of assimilates being directed toward the roots. In both cases, the result will be a lower level of total growth, as long as the canopy is operating efficiently.

A special circumstance occurs when the prelopped canopy was photosynthetically ineffective (because of aging, hedgerow grass sward, or disease). In this situation, removing part of the canopy and allowing it to be replaced by younger, photosynthetically more efficient leaves can result in a somewhat greater amount of total growth (renewal pruning).

Managing hedgerows

Lopping aerial parts of woody plants can result in a reduction of the subsequent total biomass increment; of this increment, however, a higher proportion will be new leafy shoots. The key to optimizing production is to adjust the frequency and intensity of lopping so that the increase in leafy shoots is greater than what could have been obtained without pruning. Total biomass increment usually decreases with increased frequency of lopping (Table 2).

Table 2. Annual biomass production (kg/tree, dry weight) from *Erythrina poeppigiana* pollarded once, twice, and three times per year in Turrialba, Costa Rica.

Pollarding inverval (months)	Leaf biomass	Branch biomass	Pollarded total biomass
12	11.7±3.4 (3270)	54.3±13.8 (15200)	66.0±17.2[a] (18470)
6	13.9±4.0 (3900)	28.2±8.1 (7900)	42.2±12.7[b] (11800)
4	15.5±5.0 (4340)	12.5±4.9 (3510)	28.0±9.8[c] (7850)

Note: Values in parentheses are biomass production in kilograms per hectare (280 trees/ha, corresponding to a spacing of 6 × 6 m).

Source: Russo and Budowski (1985).

[a] Data from 24 trees, one pollarding.

[b] Data from 48 trees, sum of two pollardings.

[c] Data from 12 trees, sum of three pollardings.

Fine-root turnover

New discovery

One of the most interesting recent discoveries from detailed study of the carbon budgets of selected tree species is that a considerably higher proportion of dry matter can be allocated to root growth and respiration, especially fine-root turnover, than was previously thought (Bowen 1985; Cannell 1985). In some cases, for example, where trees are growing on nutrient-depleted sites (McMurtrie 1985), 40–60% of the total carbon fixed in one season is allocated to root growth and respiration (Table 3).

This discovery has several implications to agroforestry in general and hedgerow intercropping in particular. For example, the amount of organic carbon being returned to the soil through fine-root death and decomposition (and perhaps root exudates) could potentially be as high as that expected from leaf litter.

Table 3. Recent high estimates of root biomass increment of selected plant species.

	Net annual production (t/ha)				
Species	Stemwood/ stembark	Branches	Fruits etc.	Foliage	Roots (est.)
Picea sitchensis (UK)	16.43	4.30	—	6.01	5.28[a] 3.15[b]
	Natural deciduous forest				
Liriodendron tulipifera	1.11	0.57	0.20	3.09	2.55[c]
With *Quercus* spp.	0.39	0.46	—	—	
Pinus echinata (USA) (woody litter)[d]	0.59	0.02	0.50	0.37	
Carya tomentosa (understory)	0.52	0.04	0.02	0.10	
	Second-generation forest				
Pseudotsuga menziesii (USA)	1.37	0.27	—	2.41	9.16[e]
Castanea chrysophylla	—	—	—	—	
Alnus rubra	—	—	—	—	
	Experimental forest				
Pseudotsuga menziesii (USA)	4.30	—	—	—	8.5–10.2
Tsuga heterophylla	0.60	—	—	—	
Shrubs	0.40 (losses)	—	—	—	

Source: Huxley (1986), extracted from Cannell (1982).
[a] Fine roots.
[b] Thick roots.
[c] Subsequently reestimated at 9.0 t/ha per year.
[d] Understory shrubs.
[e] With estimated turnover of mycorrhizal roots.

To date, evidence has shown that any system of continuous cropping and harvesting is likely to cause soil deterioration. With acid and low-activity clay soils (Oxisols and Ultisols), this deterioration can happen rapidly. Even when continuous cropping is accompanied by regular additions of mulch or manure, problems of soil nutrient imbalance or adverse soil reaction may be responsible for declining crop yields. Some form of soil amelioration (addition of P fertilizers or lime) will eventually become necessary, even with relatively favourable systems, such as pastures.

The reported annual amount of plant residues available for soil amelioration from hedgerow intercropping varies between 3 t/ha in semi-arid regions to 8–10 t/ha in the humid tropics. Unless the soils are intrinsically poor to start with, even the higher level may be insufficient to improve soil productivity. If hedgerow loppings are to be removed for fodder or fuelwood, any potential for long-term soil improvement will obviously be reduced.

There is, perhaps, an unfortunate emphasis on nitrogen as a key element in soil fertility. A balance of all other soil nutrients and soil physical conditions should not be disregarded. Glover and Beer (1986), from various experiments carried out in Central America, emphasized the significance of the amounts of other nutrients added in litter or residues. Research is needed on the broader issue of the potential of residues from multipurpose trees for soil enrichment. The rate at which possible long-term soil changes may occur also needs further study. In many cases (e.g., microsite enrichment), an ecological rather than an agricultural time scale may be pertinent.

Short-term soil changes

The short-term effects of applying plant residues to soil can be considerable, particularly in the promotion of root growth and the activity of crop plants. These short-term effects also include improving both the timeliness and availability of water and nutrients in the topsoil, as well as improving crop seed germination in hot regions by lowering soil temperatures. These effects are important in low-rainfall areas and on nutrient-depleted soils. There may also be some beneficial effects of shelter through reduced wind speeds and improved temperature/humidity regimes.

If the potentials of tree/crop mixtures, such as hedgerow intercropping, are to be exploited and extended to regions with less favourable environments, then the short-term processes that may contribute to the system's success must be investigated. The likely magnitude of these processes under a wide range of environmental conditions must also be studied.

Tree/crop mixtures

Modeling

When creating a tree/crop mixture, a good first step is to know what will happen under a single tree or small group of trees of one species. What will happen in the tree/crop mixture is a much more complex problem. A tree/crop mixture can be modeled (Fig. 3) for changes with time, considering only soil factors, plant factors, or a combination of both, to indicate the state of land productivity as a whole. This model has been discussed in detail elsewhere (Huxley 1983b, 1985b, 1986).

Some information is available from experiments in the tropics about long-term soil changes under different agricultural crops. Little is known, however, about soil changes under multipurpose tree species. There are some theoretical approaches to predicting expected changes with time under different circumstances (of soil organic carbon, for example; Young 1986). However, researchers know little of what happens under tree/crop mixtures. Therefore, it is hard, at present, to define the exact shape of the response surface.

Occupancy: space vs time

On moderately fertile soils and with sufficient rainfall to promote a reasonably high potential level of biomass production (yearly rainfall of 1 000 mm), hedges 4–5 m apart maintain sustainable crop yields (see other papers in this volume). This kind of system has only 20–25% spatial cover; the cover will be less where hedges are farther apart.

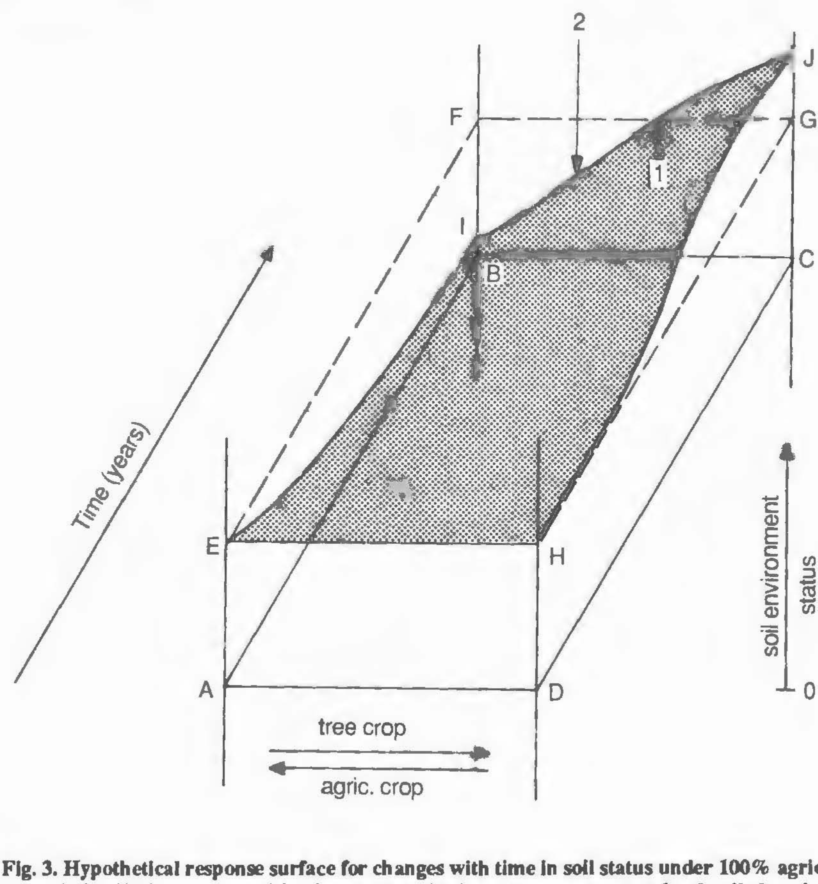

Fig. 3. Hypothetical response surface for changes with time in soil status under 100% agricultural crop (left), 100% tree cover (right), and all ratios in between — see text for detailed explanation (source: Huxley 1986).

In Fig. 3, the vertical axis represents soil fertility status, which is shown declining with time under agricultural crop (E to I) and improving under tree cover (H to J). As modeled, at the end of the time shown, the level of soil fertility would be maintained by the ratio of tree crop cover indicated by the arrows on FG (1). A 25% tree cover (hedges) would give the fertility indicated at 2.

The small proportion of trees in this mixture is not enough to maintain soil fertility, according to the conditions chosen in this particular model (Fig. 3). One of three responses is needed: either a relatively smaller decrease in soil fertility under continuous cropping, a much greater improvement in soil fertility under a full cover of trees, or a much greater improvement as a result of the mixture of trees and crop (a highly convex response surface). The researcher can decide whether either of the first two choices is possible for a specified site. If they are not, or if they still do not adequately improve the situation at the 20–25% level of spatial cover, then the conclusion may be that hedgerow intercropping can confer some substantial benefits on crop associates (benefits that are not obtained by crops following on rotationally after a full cover of trees grown alone).

In comparison, in a bush-fallow system with a fallow of 12–15 years followed by 3 or 4 years of cropping, the tree cover becomes 80% or more. Even if one assumes that the tree canopy will not effectively cover the ground for the first few years, there is still a large discrepancy with regard to crop output with equal proportional tree cover in space (e.g., hedgerow intercropping and time (rotational plantings). For further discussion about these processes, see Huxley (1986).

All these facts support the argument that a major set of influences responsible for successful crop production in spatially separated tree/crop mixtures (and especially where the trees are intermittently lopped and the plant residues retained on site) are likely to be short term. If, on appropriate soil types, long-term soil changes are to be a serious objective for hedgerow intercropping schemes, then some system of alternating the between-hedge cropping cycles with periods when the hedgerows are allowed to grow, deposit litter, and accumulate biomass (all of which is left on the site) will probably be needed. These rotational hedgerow schemes (see Reynolds and Atta-Krah, this volume) need to be explored more fully because they can combine both the short- and long-term soil benefits that the model prompts us to compare.

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Part 7

Networking and Collaboration

Collaboration in alley farming research

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Abstract — Alley farming affords the opportunity for agronomists, animal scientists, socioeconomists, and foresters to collaborate to improve the livelihood of farmers of Africa. The history of alley farming and alley cropping is discussed. Concepts of networking for Africa are presented.

Introduction

This workshop is an attempt to examine and focus on an overall strategy for alley farming as one important component of agroforestry — how to improve the amount of land under continuous production for food crops and maintain soil fertility. Alley cropping is observed to be a viable alternative where bush-fallow and slash-and-burn agriculture is being practiced.

Some researchers report that the biomass produced by widely spaced trees pruned periodically may be too low to really add significant amounts of organic matter. However, Kang et al. (1984) found, over a 3-year period in Ibadan, that the annual yield of *Leucaena* prunings averaged 6.7 t/ha of dry matter. This is considerably less than what the production of solid forestry plantings might be. However, when the residues of the interplanted food crops in alley farm are added to the *Leucaena*, a considerable sum of organic matter is being returned to the soil. For example, the harvest index of tropical maize is generally 1:2; that is, one part of grain to two parts of stalk, leaves, and roots. So, if a grain yield of 1 t is obtained, 2 t of residues remain for soil building.

Long-term trials on maize at the International Institute of Tropical Agriculture (IITA) indicate that, with good management, an annual yield of 3–6 t/ha of grain is possible. In some areas, considerable organic matter is being returned to the soil, where about 6 t/ha of *Leucaena* prunings as well as 6–12 t/ha of maize residues are being added yearly. Hybrid maize may increase this total and the residues of a second-season cowpea crop could add approximately 1 t of high-nitrogen residues.

History

Alley farming trials began at IITA shortly after the Institute's research program began. A yam-*Leucaena* staking experiment was conducted in 1973; in 1975-76, several trials were established that still exist today. Early trials used the legume species, *Leucaena leucocephala*. *Gliricidia sepium* was introduced in 1977 and, more recently, *Flemingia congesta*. Nonleguminous species in experimental plots at IITA headquarters are *Alchornea cordifolia*, *Acioa barterii*, and *Gmelina arborea*. Many of these same species are being used in studies at Onne, the substation near Port Harcourt in southeastern Nigeria. This location has acid Ultisols (pH 4.5); therefore, responses are different from those at trials on the Alfisols of Ibadan (pH 5.6).

In 1979, B.T. Kang established an observational nursery at IITA, Ibadan, and Onne. The nursery included 34 legume and nonlegume forestry species and varieties. Since 1980, 30 on-farm alley farming trials have been established by IITA; many more were started in 1981 by the International Livestock Centre for Africa (ILCA). Most of the ILCA trials also involve feeding studies for small ruminants.

Training

IITA and ILCA are, at present, offering 3-week training courses on alley farming in Ibadan. Three 1-week training courses have been carried out in collaboration with the Food and Agricultural Organization and the Federal Department of Forestry in Nigeria. IITA and ILCA have also offered technical training courses.

Collaborative research

A collaborative research network for alley farming should include on-station and on-farm component research experiments. Perhaps more emphasis should now be placed on on-farm research. This will not be easy in Africa and, therefore, considerable attention and training must be devoted to methodology during the early years.

One method that might be adapted for alley cropping was formulated by the Asian Cropping Systems Working Group in collaboration with the International Rice Research Institute (IRRI). It aims for a manageable research process that is particularly suited for small farms and that treats agricultural research as dependent on site. The research activities, therefore, focus on the description and classification of the environment, on the design of improved cropping systems, on the testing of these systems on individual farms, and on formulating production programs.

This model was originally designed for cropping systems but could easily be adapted for alley farming. The following paragraphs describe the phases of on-farm research in this model.

Site selection

One or more geographical areas representative of a large, homogenous production zone are selected. The areas should be earmarked for development by the national government. In this way, support for production programs will be given when the potential for production increases has been demonstrated.

Site description

When researching cropping patterns, the first activity is to describe existing patterns, the physical environment, constraints to production, and the socioeconomic environment. The characteristics of the farm environment will decide research priorities at the site and supporting research stations. At this time, the area is also divided into different land types, each of which may require a different production recommendation.

Cropping-pattern design

Designing cropping patterns includes designing alternative patterns that are well adapted to the area: patterns that consider physical and socioeconomic characteristics, the performance of cropping patterns, and the available technology for the crops in the pattern. There are numerous practices that must be specified for all crops in each pattern. Many can be specified on the basis of existing knowledge and local methods. Others warrant separate experiments to establish optimal input levels. This component-technology research may be conducted in national, regional, or other experiment stations, or at the cropping research site.

Testing cropping patterns

The designed cropping patterns and selected management components must be tested in their respective environments in farmers' fields. Farmers participate in the testing by managing the patterns with frequent advice and constant monitoring from research staff. Based on the agronomic and economic performance of these cropping patterns, problems that would limit intensification of production can be identified and fed back to discipline- or commodity-oriented researchers. This scheme helps orient the research to solve the specific problems of the target farmers.

Applied research

The most profitable cropping pattern from the testing phase should be evaluated in many sites within the environmental complex for which they were designed. In this phase, the researchers should include other institutions responsible for formulating and implementing production programs.

Production program

As soon as promising cropping patterns are identified and their management is specified, a production program can be started by extension institutions. The research team should be involved in formulating the program and training the extension workers who will be involved.

Networking

Perhaps "networking" is a buzzword of the 1980s; however, many agricultural-development leaders believe networking to be one of the most viable ways to transfer improved technology to national programs or institutions. A recent survey in sub-Sahelian Africa indicated that 24 networks were being conducted by French government agencies and that 27 others existed among international agricultural research centres (IARCs), regional programs, and national programs (R.W. Cummings, personal communication, 1986). There are three types of networks:

- *Information-exchange networks* organize and facilitate exchange of ideas, methodologies, and results of current research.
- *Scientific-consultation networks* involve a country-by-country focus on important common research areas. These projects are initiated and implemented independently by the participating institutions that meet regularly and provide other means to exchange information on research (as in information-exchange networks).
- *Collaborative-research networks* involve joint, intercountry planning, implementing, and monitoring of research on problems of mutual concern to countries within a region. These networks could include information exchange, technical collaboration, and training.

There are 18, 14, and 19 information-exchange, scientific-consultation, and collaborative-research networks in Africa, respectively. Numerous donors are involved and several donors often jointly support the same network. At least seven of the CGIAR-supported international research centres are represented.

IITA participates in the following networks and sends out additional specific germ-plasm nurseries on country requests:

- Semi-Arid Food Grain Research and Development Project (SAFGRAD) (maize and cowpea): 26 semi-arid African countries.
- European Economic Community – High Yielding Varieties Technology Project (EEC–HYVT) (maize, rice, cowpeas, and soybeans): 25 African countries with humid regions.
- African Biological Control Programme (ABCP).
- International Rice Testing Programme (IRTP) — Africa: cooperation with IRRI and the West African Rice Development Association (WARDA).
- West African Regional Cooperative for Research on Plantains (WARCORP).
- West African Farming Systems Research Network (WAFSRN).

Collaborative research is also needed for root and tuber crops in East, Central, and Southern Africa; cowpeas in the sub-Sahelian areas; *Striga* spp. and *Imperata cylindrica*, which are two devastating weeds of Africa; and alley farming.

Successful networks use the bottom-up approach; i.e., the national program defines objectives and needs and the IARC provides training, coordination, facilities, germ plasm, and back-up research. Networks can be simple and narrowly defined or broad based. An example of a broad-based network is SAFGRAD. It deals with the improvement of several crops and involves several national and international institutions.

To succeed, a network needs common objectives, agreed upon by all parties, and a full-time coordinator. The coordinator, who must be a knowledgeable and respected scientist, is usually the key to a network's success and must motivate and plan. Ideally, the coordinator should have no other duties and assignments. A network requires annual workshops or planning meetings during which its progress is reviewed, objectives redefined, methodology discussed, and duties assigned by country and coordinator. Other requirements for a viable network are monitoring tours, back-up research, and training.

One network in which IITA is involved is WARCORP. Dr George Wilson of the Farming Systems Programme spends about 80% of his time as the coordinator of WARCORP. The cooperative aims of WARCORP are to improve plantain production by:

- creating an awareness of the importance of plantains;
- strengthening national research capabilities;
- coordinating research to reduce repetition and duplication;
- rapidly disseminating findings and recommendations;
- training research, extension, and production personnel; and
- encouraging national and international support for research and development.

Decisions on experiments are made at WARCORP's annual meetings, usually held in December. The experiments are chosen based on the priorities of the region or country; the cooperative's priorities; the interest and specialization of the scientist; and the funds available. At the meetings, which rotate among countries and research institutions, scientists report not only on research supported by WARCORP but also on related work supported by their institutions and other sources. (For more information, consult *IITA Research Briefs*, 6(1), March 1985.)

Research needs

Management studies must involve the systems approach, not only of the food crops but also of the alley crop species. How can the aboveground and below-ground competition be reduced? What are the various trade-offs between crop yields, economic returns, and environmental conservation? What are the on-farm constraints to alley farming? Planting trees is alien to a farmer in the humid or subhumid areas. They have cut and burned trees all their lives — never planted them. Alley farming is a technology that will require more education than other improved technologies. There are also social challenges, such as land tenure, that must be recognized.

ILCA (1985) has reported promising results from browsing and cut-and-carry systems that use the alley farming system. However, much more research is needed. The Technical Advisory Committee recommended to CGIAR, in its 1985 priorities for international agricultural research, that the present allocation for resource management and conservation research be increased from 7 to 16% (Swaminathan 1986). Alley farming certainly merits inclusion in such new funding endeavours: it not only seeks to better manage a farmer's resources for higher productivity but also tries to conserve the farm for future generations. The old saying of "one should live today as if it were the last, but a farmer should farm as if it were forever" is true.

IITA and ILCA seek to be catalysts in imparting greater relevance to the research priorities and strategies of national and regional institutions. Both institutions can more easily identify and solve the knowledge gaps of alley farming through the power of cooperation. What will be the on-farm constraints in different agroecological areas? If each cooperating institution can study a piece of the puzzle, then the final solution will be accelerated. Alley farming must not only make practical sense but also economic cents for the farmer.

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Networking activities with specific reference to alley farming

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Abstract — This paper discusses the beneficial effects of networking as a method for solving national, regional, and global agricultural problems. The principles for developing an alley farming network for Africa are presented.

Introduction

Networking in agricultural research in Africa is now receiving top priority by many international donors, including the International Development Research Centre (IDRC) in Canada and United States Agency for International Development (USAID). Country programs are considered as the most important in building up independent, self-sustaining capabilities. However, because of the lack of bilateral programs, "quick-fix" regional programs have often been sanctioned and implemented — and not always with the most beneficial results.

Networking is defined as "the establishment of a system or arrangements to work on a common crop, commodity, or problem. The system may comprise individuals, groups of individuals, or institutions interested in solving a common problem" (USAID 1985b). The variety and number of donors, combined with restricted funding, make networking very attractive for the following reasons:

- facilitates communication or technology transfer;
- fosters collaboration and coordination in research efforts, rather than isolated, individual projects;
- makes efficient use of existing information to generate new knowledge;
- identifies specific components for members to focus on and avoids duplication and waste;
- concerted attention by members can increase the program's success;
- more cost effective; and
- combined efforts by industrial countries, developing nations, and international agricultural research centres (IARCs) can provide the needed

Table 1. Selected international agricultural research networks.

Network[a]	Coordinators[b]	Region(s)	Countries	Year started
IBYAN	CIAT	Worldwide	30	1976
CEAREP	CIMMYT	East Africa	14	1976
PRAPAC	CIP	Central Africa	4	1983
IPMAT	ICRISAT	Asia, Africa, Latin America	22	1975
ISVAT	ICRISAT	Worldwide	37	1977
ARNAB	ILCA	Africa	6	1980
Trypano-tolerance	ILCA/ILRAD, ICIPE	Africa	9	1983
INSFFER	IRRI/IFDC	Asia, Africa	19	1976
IRTP	IRRI/IITA, WARDA	Worldwide	75	1975/85
WAFSRN	IITA/Ford Foundation	West Africa	10	1983
INTSOY	Universities of Illinois and Puerto Rico	Worldwide	70	1973

[a] IBYAN, International Bean Yield and Adaptation Network; CEAREP, CIMMYT East African Regional Economic Programme; PRAPAC, Programme régional d'amélioration de la culture de pomme de terre en Afrique centrale; IPMAT, International Pearl Millet Adaptation Trial; ISVAT, International Sorghum Variety Adaptation Trial; ARNAB, African Research Network for Agricultural Byproducts; INSFFER, International Network on Soil Fertility and Fertilizer Evaluation for Rice; IRTP, International Rice Testing Program; WAFSRN, West African Farming Systems Research Network; INTSOY, International Soybean Program.

[b] CIAT, International Centre for Tropical Agriculture (Cali, Colombia); CIMMYT, International Centre for Maize and Wheat Improvement (Mexico City, Mexico); CIP, International Potato Center (Lima, Peru); ICRISAT, International Crops Research Institute for the Semi-Arid Tropics (Hyderabad, India); ILCA, International Livestock Centre for Africa (Addis Ababa, Ethiopia); ILRAD, International Laboratory for Research on Animal Diseases (Nairobi, Kenya); ICIPE, International Centre of Insect Physiology and Ecology (Nairobi, Kenya); IRRI, International Rice Research Institute (Los Baños, Philippines); IFDC, International Fertilizer Development Center (Muscle Shoals, USA); IITA, International Institute for Tropical Agriculture (Ibadan, Nigeria); WARDA, West African Rice Development Association (Monrovia, Liberia).

organization that is more likely to attract international and multidonor support (CGIAR 1983).

All 13 of the IARCs have collaborative programs in Africa (Table 1). The two networks with the largest worldwide programs are the International Rice Testing Programme (IRTP) and the International Soybean Programme (INTSOY), involving trials and activities in about 75 countries.

Types of networks

Networks vary as much as their subject, but there are two basic types: formal and informal (Plucknett and Smith 1984). Informal networks vary in size and magnitude, from individuals to groups of individuals interested in a common cause or theme. With advanced programs and extended activities, formal networks are developed. Today, there are more than 100 different networks involved in a wide variety of international agricultural projects (Plucknett and Smith 1984). A nucleus or hub is required for a network to exist (Fig. 1). As the network develops, the satellite participants assume a larger proportion of activities in specialized areas and become more independent. Ultimately, they will interact among themselves. The original centre or hub will always be responsible for communication and administrative/financial activities.

The prerequisites for establishing a successful network include a common goal or problems of mutual interest. According to Odhiambo (1983), there are seven prerequisites:

- The problem should be clearly defined and a realistic agenda drawn up;
- The problem must be widely shared by the would-be participating countries;
- There must be self-interest, rather than mandating, by the participants;
- Participants must be willing to commit resources, such as personnel and facilities, to the program;
- There is always need for outside funding to facilitate operations, training, and international travel, particularly in the Third World;

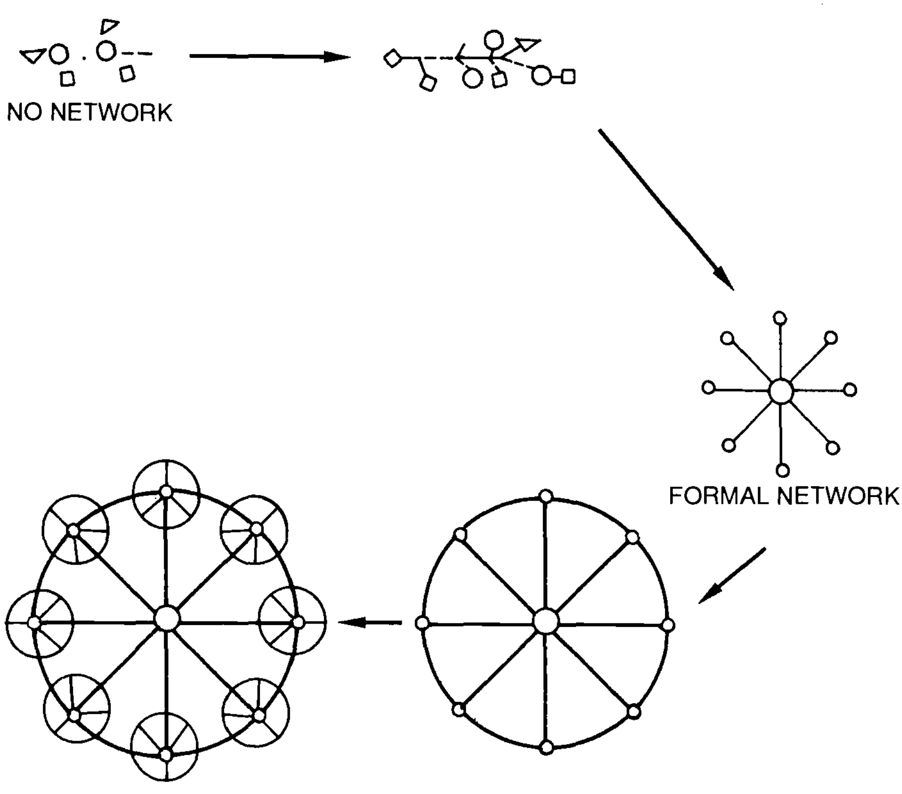

Fig. 1. Schematic diagram of networking — relationships become more complex as the network evolves more than one wheel (adapted from CGIAR 1983).

- Participants must have sufficient training and expertise to make a contribution; and
- Leadership of the program should be strong, efficient, and recognize the contribution of each participant.

USAID has a special commitment to natural resource management programs in Africa. An indication of the agency's proposed activities in this area can be gleaned from a direct quote from the 1986 Congressional Record (USAID 1985a:19):

> The advance of the desert, the denudation of the forest, and the depletion of the soil which the continent is witnessing seriously undermines agricultural production and threatens future growth.

Growing populations and their expanding demands for food, fuel, fodder, and shelter have led to the exploitation and destruction of natural resources at a much faster rate than can be naturally replaced. African woods and bush are being cut down for fuel and new farmland at a rate of 1.3×10^6 ha/year. This has resulted in the accelerated degradation of watersheds, water supply, soils, and fuel-crop yields. In addition to crop shortages, fuelwood shortages already affect 180 million people in 34 African countries. Consequently, the tasks of arresting environmental deterioration and regenerating existing soil, water, and forest resources command high priority among USAID's development goals. Over the past 7 years, USAID has committed a total of USD 55 million in forestry and fuelwood projects and another USD 80 million in closely related natural-resources and renewable-energy projects (50 projects in 26 countries). Over the same period, USD 125 million was committed to activities supported by Public Law (PL) 480. (PL 480 is a program whereby the United States supplies surplus agricultural products at reduced cost to Third World countries; this generates local currency for the development of local projects.)

As outlined by Plucknett and Smith (1984), network activities, in order of priority, include research coordination, training, information exchange, and the transfer of newly developed technologies. Research coordination has been singled out as the most important aspect of networking. Because of the number and extent of donor activities in Africa, there is often extensive repetition or overlap in activities.

As previously mentioned, all 13 IARCs have programs in Africa; the cooperative efforts of many of the institutes are exemplary. The Nairobi Cluster (1981), an example of national and international collaboration, comprises 22 advanced research institutes working on animal diseases; all these institutes have their offices and laboratories in Nairobi, Kenya. Quarterly meetings are held to review, discuss, and outline proposed programs to avoid duplication. This type of collaboration is not only commendable but also necessary in any networking activity.

National and international collaboration and support

The status and viability of networks are affected by the type of collaboration and donor support. With the variety of donors operating in Africa and the large number of ongoing programs, there is a need to provide sustained, recurrent expenditures for the continuity of programs. Cooperation is therefore a necessity. As related to agroforestry and especially alley farming, recent USAID support to individual national projects in tropical Africa totals USD 405.3 million, in part for cereal production from tree-enhanced sites (Catterson and Prussner 1985).

Bilateral funding is preferred by many countries. Too frequently, they feel they have not benefited sufficiently from regional activities. There have been accusations that monies are not distributed equitably throughout the countries of the region, and headquarter staff and the host country receive the majority of the benefits. With USAID, the preference for country-specific activities is reflected in the 10:1 bilateral/regional ratio. Mission funding of programs — including training, the second-most important aspect of networking — is an area that must be emphasized in gathering support for network activities such as alley farming.

Many countries receive support under PL 480, which generates local currency for self-help, transport, marketing, and distribution activities. The African recipients of PL 480 include Burkina Faso, Cape Verde, Mali, and Mauritania. The basic objective of these programs is to curtail hunger and malnutrition and improve the livelihood and health of the population. Various bilateral aid funds exist that could support alley farming programs.

Cooperation for Development in Africa (CDA) is a cooperative network for medium and long-term planning and assistance for Africa. It is an informal association of seven donor nations that support major development activities in Africa. Member countries include Belgium, Canada, France, Italy, United Kingdom, United States, and Federal Republic of Germany. The purpose of CDA for sub-Saharan Africa is to identify projects jointly with Africans, to coordinate resources, and to implement projects, with the overall objective of increasing productivity.

Major initiatives identified by CDA include agricultural research; energy; childhood communicable diseases; appropriate rural technology; irrigated perimeters; forestry fuelwood; and transportation in southern and central Africa. Technical coordinators are supplied by donor nations.

CDA's work on agricultural research is based on agroclimatic zones. The United States is the overall coordinator, in addition to coordinating work in the Sahel and the southern African plateau. The United Kingdom coordinates work in the Sudan; Canada is responsible for East Africa; West Germany oversees work in coastal West Africa and Belgium in the Congo River basin. France is the back-up coordinator in several of the zones.

USAID looks forward to the possibility of developing and continuing network activities in alley farming. There is tremendous potential in the adoption of alley farming and, with the present rate of population growth, alley farming is a practical method of reducing fallow periods. The advantages of alley farming and the reduction of cost for inputs such as fertilizer lend credence and importance to this type of activity. Alley farming is only one of the needed activities to assure food security in Africa.

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Part 8

Recommendations and Appendices

Recommendations

Topics for study

Systems description

Recommendation domains must be identified in terms of agroecological, socioeconomic, physical, and biological variables.

On-station studies

The following six points require on-station action:

- site adaptability and identification of trees for different physical environments including acid soils, tropical highlands, and semi-arid areas;
- optimization of the use of material from trees in crop and livestock systems;
- testing of germ plasm for specific feeding qualities and chemical properties;
- evaluation of a wider range of food crops to be included in alley farming;
- investigations on basic soil, plant, and water relationships in alley farming; and
- regional coordination and standardization of methodology.

On-farm studies

On-farm studies should involve the development and evaluation of alley farming. This should be an interdisciplinary study undertaken by the national collaborators. Feedback from on-farm projects will form a major component for planning on-station studies.

Organization and coordination

With respect to organization and coordination, the workshop made the following recommendations.

- An international alley farming network should be established.
- The scope of an alley farming network should be primarily the humid and subhumid zones, but arid and semi-arid areas should not be excluded.

- The executive responsibilities of the network should be discharged by a central coordinating unit to be based at the IITA/ILCA campus in Ibadan.
- There should be an international steering committee, which will have an advisory role, to represent the interests of participating countries and reflect the multidisciplinary needs of alley farming research (see Appendix I).
- Together, IITA and ILCA should pursue funding for an initial period of 5 years.
- One of the objectives of the network shall be the maintenance of communication among members.

Training

The following four recommendations were made with respect to training.

- Training experimental workers and trainers must be emphasized.
- "Training the trainer" courses should be jointly organized by ILCA and IITA with support from ICRAF (International Council for Research in Agroforestry), the Nitrogen-Fixing Tree Association, and other national and international institutions with relevant experience.
- The alley farming network should obtain funding for training activities; participants will be encouraged to seek their own sources of funding but help will be given in identifying sources of finance.
- The network and centres should provide limited follow-up support in the form of institutional materials and should arrange exchanges and visits of staff to reinforce the efforts of the participants on their return to their countries. Within the framework of the network, attempts will be made to support individual participants, especially by organizing joint projects among programs in adjacent countries.

Appendix 1. Alley Farming Steering Committee

Committee members

The following participants formed the Alley Farming Steering Committee: Drs Ebenezer O. Asare (Ghana), Jean Tonye (Cameroon), L.L.L. Lulandala (Tanzania), Aziadome Kogblevi (Benin), Denis Amara (Sierra Leone), Goodwill Okoro (Nigeria), Simeon A. Materechera (Malawi), Mr. Bianu Landu-Kalemba (Zaire), a representative of IITA, a representative of ILCA, and the Coordinator.

Plan of action

The Steering Committee formulated a plan of action consisting of the following three points:

- Government members will be sent official letters informing them of nominations to serve in the Steering Committee.
- IITA and ILCA will perform a survey to update alley farming technologies being used across participating African countries.
- Based on the survey results and if funds are available, IITA and ILCA will call a meeting of the Steering Committee to discuss activities for 1987 and to establish a network newsletter. Among other issues at that meeting, the Steering Committee will discuss ways of establishing a common methodology for alley farming research throughout Africa.

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